Search for Dark Matter Annihilations in Draco

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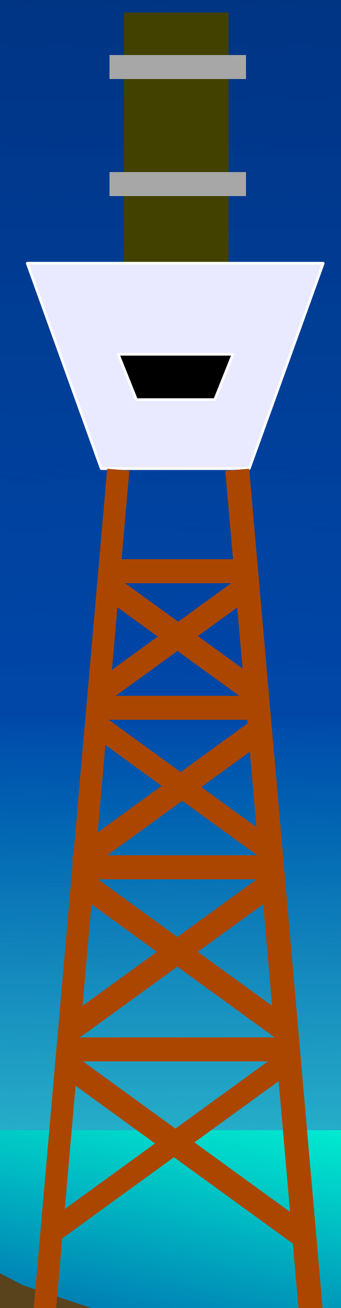
CACTUS:
A UC Davis
Facility



PANIC05, Santa Fe, Oct. 24, 2005

Outline

- Solar Two facility and CACTUS
- Instrument: 250 channel (effective) camera
- Simulations and Calibrations: optics & noise
  - Energy response
  - Crab Nebula
- The Dark Matter problem & Draco
  - Data & Preliminary analysis
- Summary and Plans

The Solar 2 Heliostat Array

CACTUS: Converted Air Cherenkov Telescope Using Solar 2

Located 15 miles outside Barstow, CA

Over 1,900 42m^2 heliostats. The largest array in the world.

We have ~160 heliostats in the FOV of our camera. Total mirror area ~6,700 m^2.

Collection (ground) area ~ 40,000 m^2

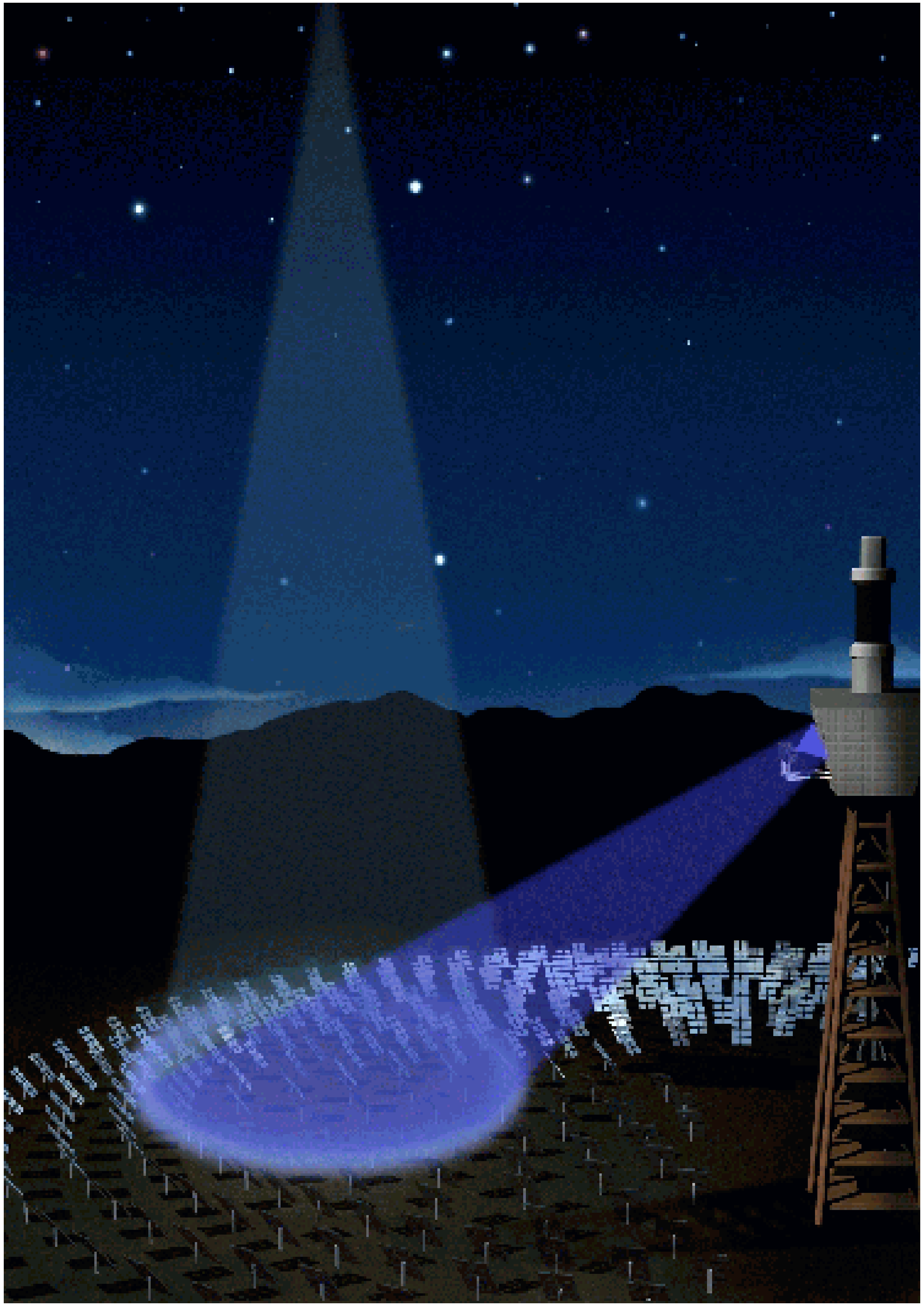
Effective (100% eff) area for E>200 GeV ~ 50,000 m^2.

Air Cherenkov

Heliostat arrays offer large collection areas that are not possible with imaging telescopes. Solar Two is the only field large enough to contain the entire Cherenkov light pool.

Utilizing existing arrays is a highly cost-effective method of constructing large area telescopes.

[Solar Two was abandoned in 1998 after a successful run as a pilot plant/technology demonstration project.]

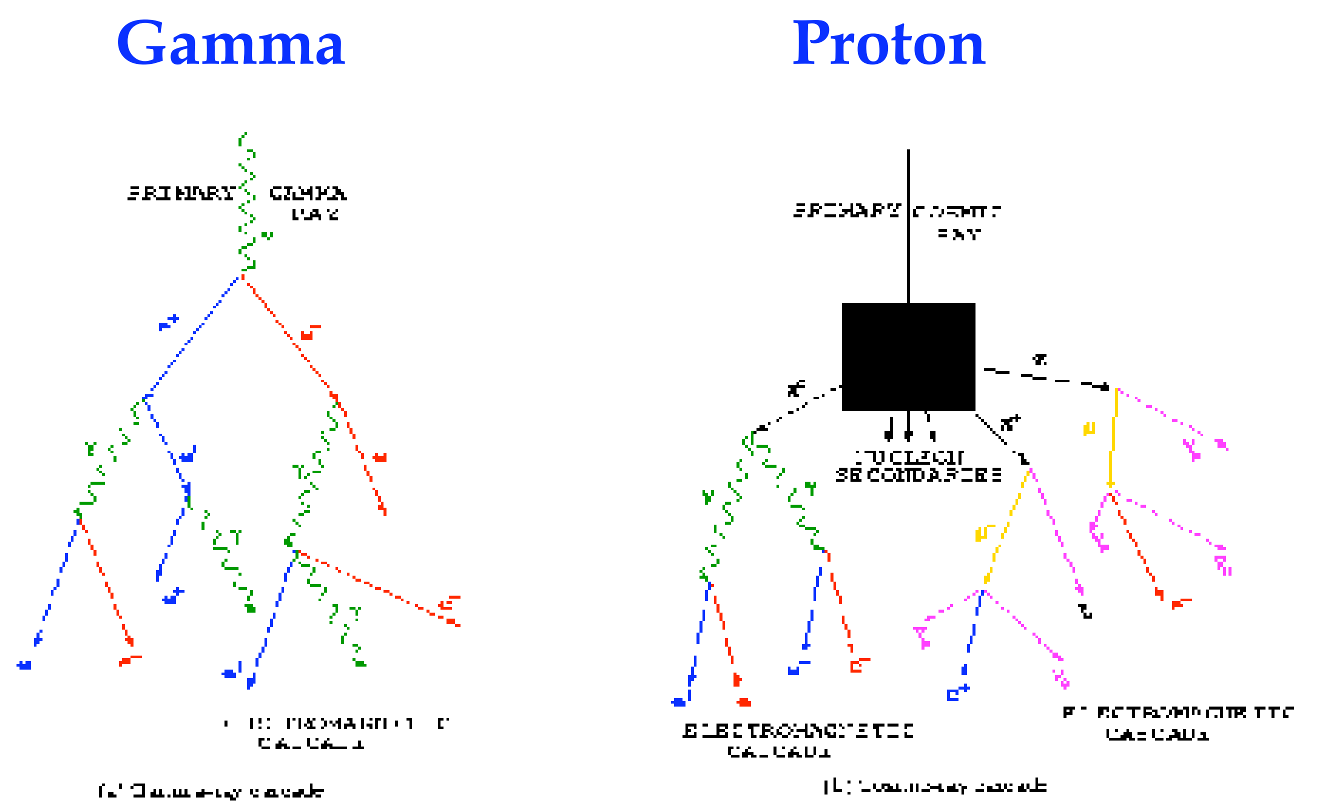


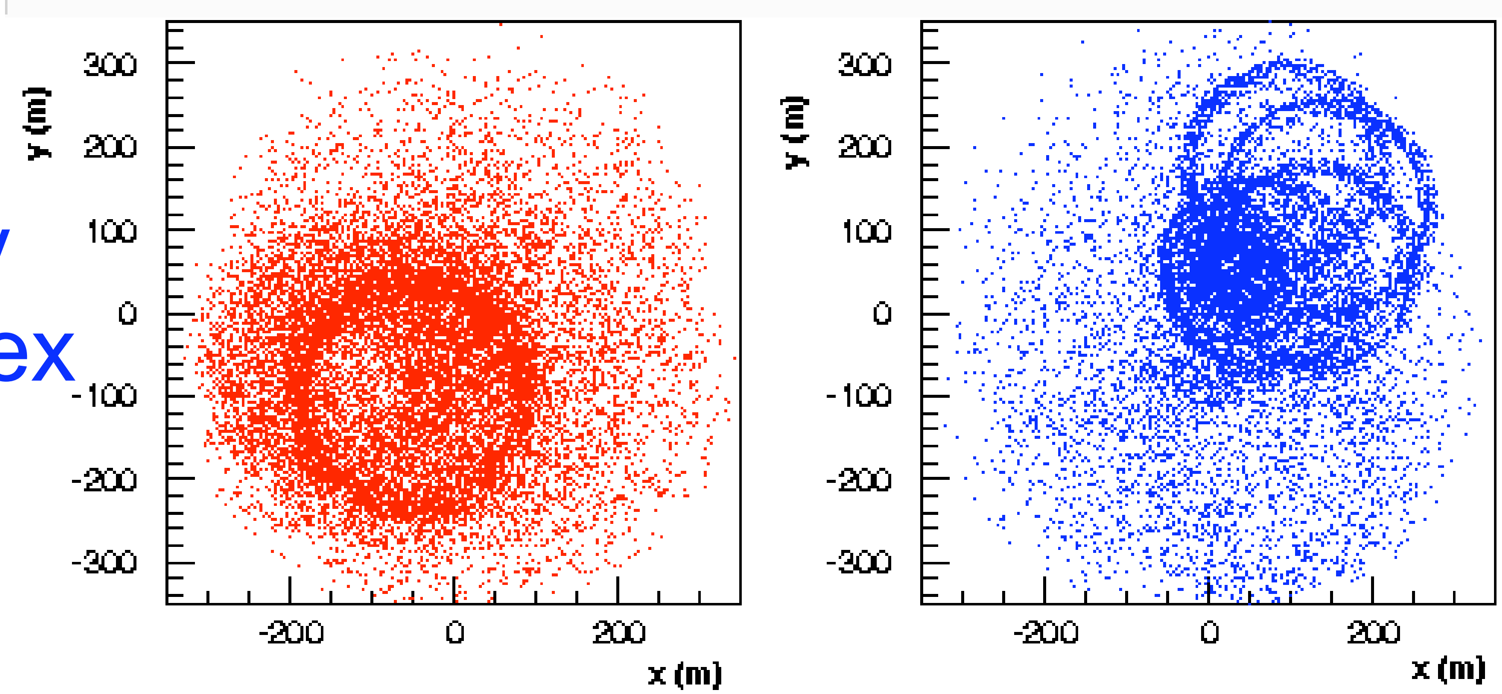
Detection Technique

EM showers produce coherent and compact ring-like Cherenkov wavefront.

Proton showers consist of EM sub-showers due to neutral pions and/or individual rings due to muons.

Core diameter of light pool nearly independent of primary particle energy (refractive index in the upper atmosphere very close to unity and radiating particles rapidly fall below the Cherenkov threshold).





Detecting Cherenkov Light

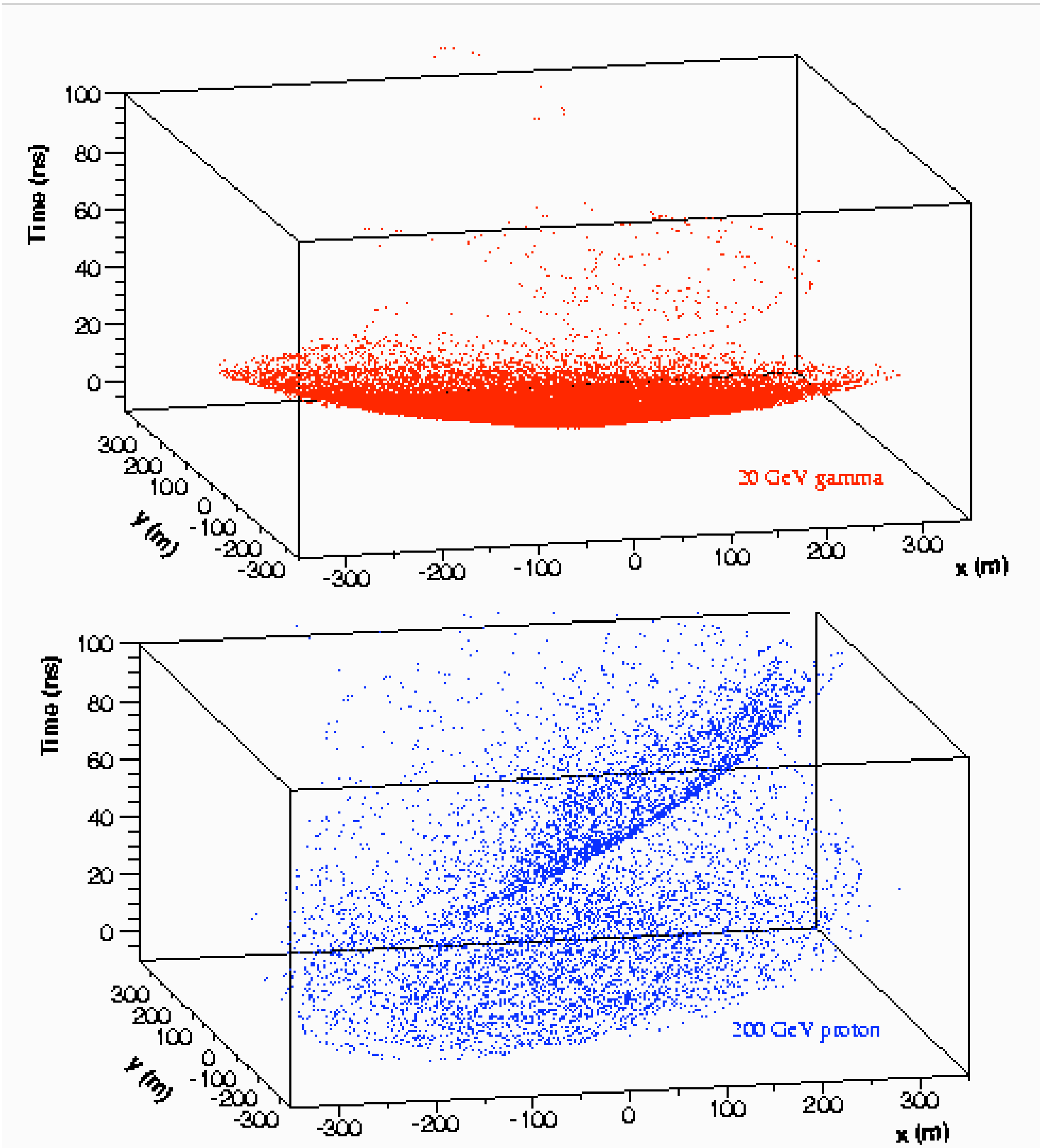
Ground based telescopes sample a fraction of the core light pool which is ~200m in diameter.

Good energy resolution demands a high photon detection efficiency.

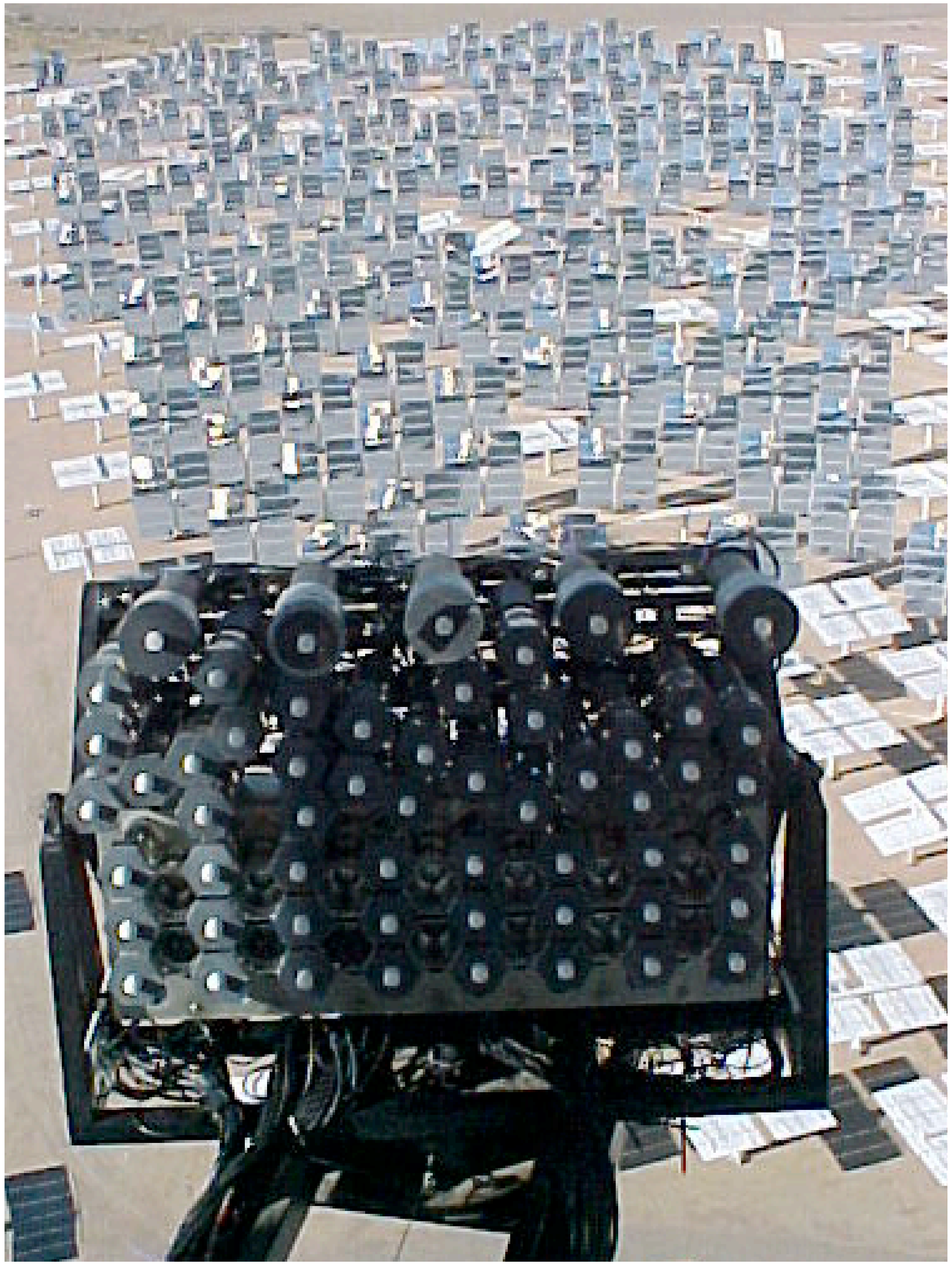
Night-sky background is in the range of ~3-6 x 10^{12} photons/m^2/s/sr.

Temporal coherence (~3-5 ns) of the Cherenkov wavefront allows for sharp coincidences between camera elements.

CACTUS can exploit differences in time-structure between gamma and proton showers.



Heliostat Field

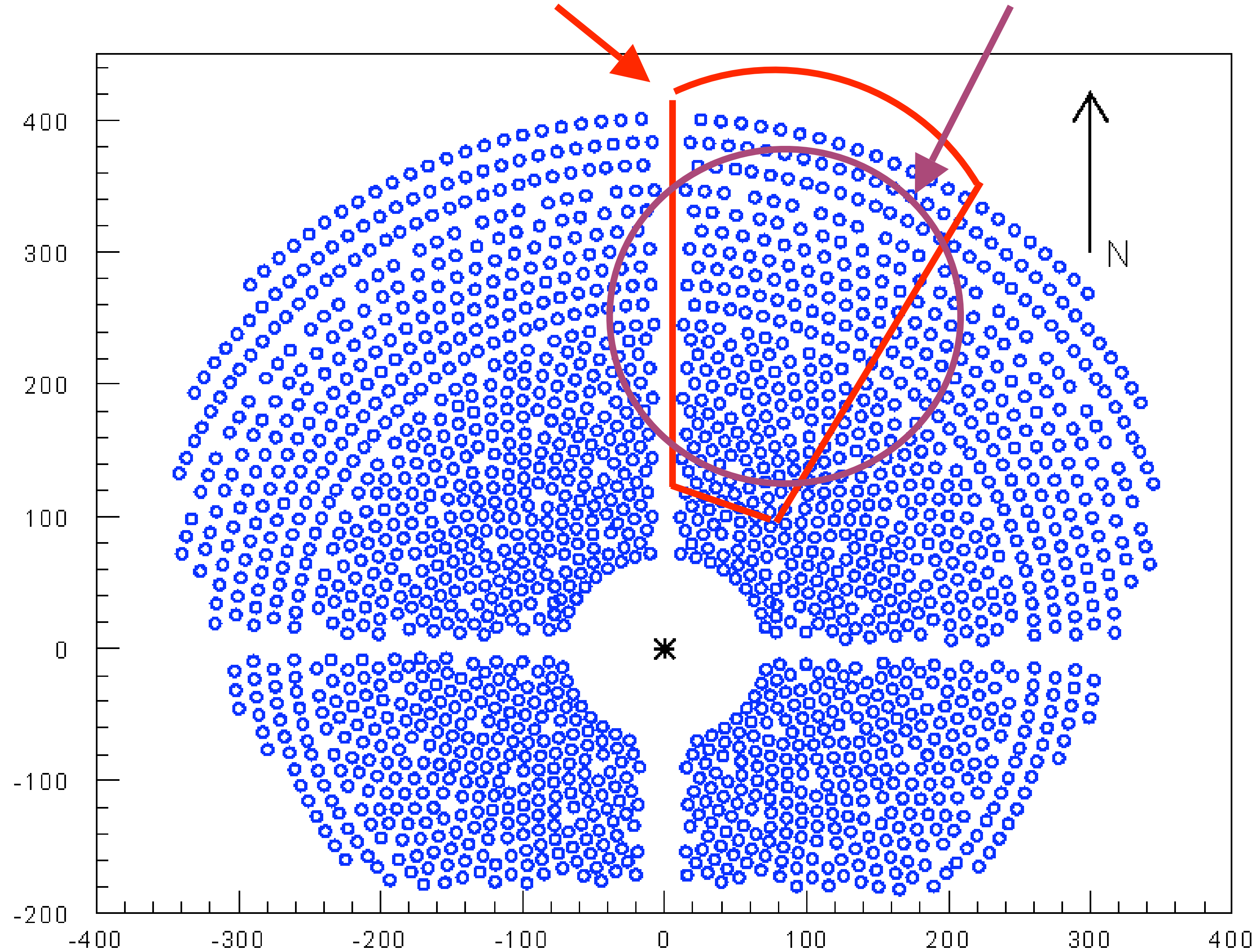


80 channel camera

Part of the field being used. 160 heliostats* available. 116-140 used in this campaign.

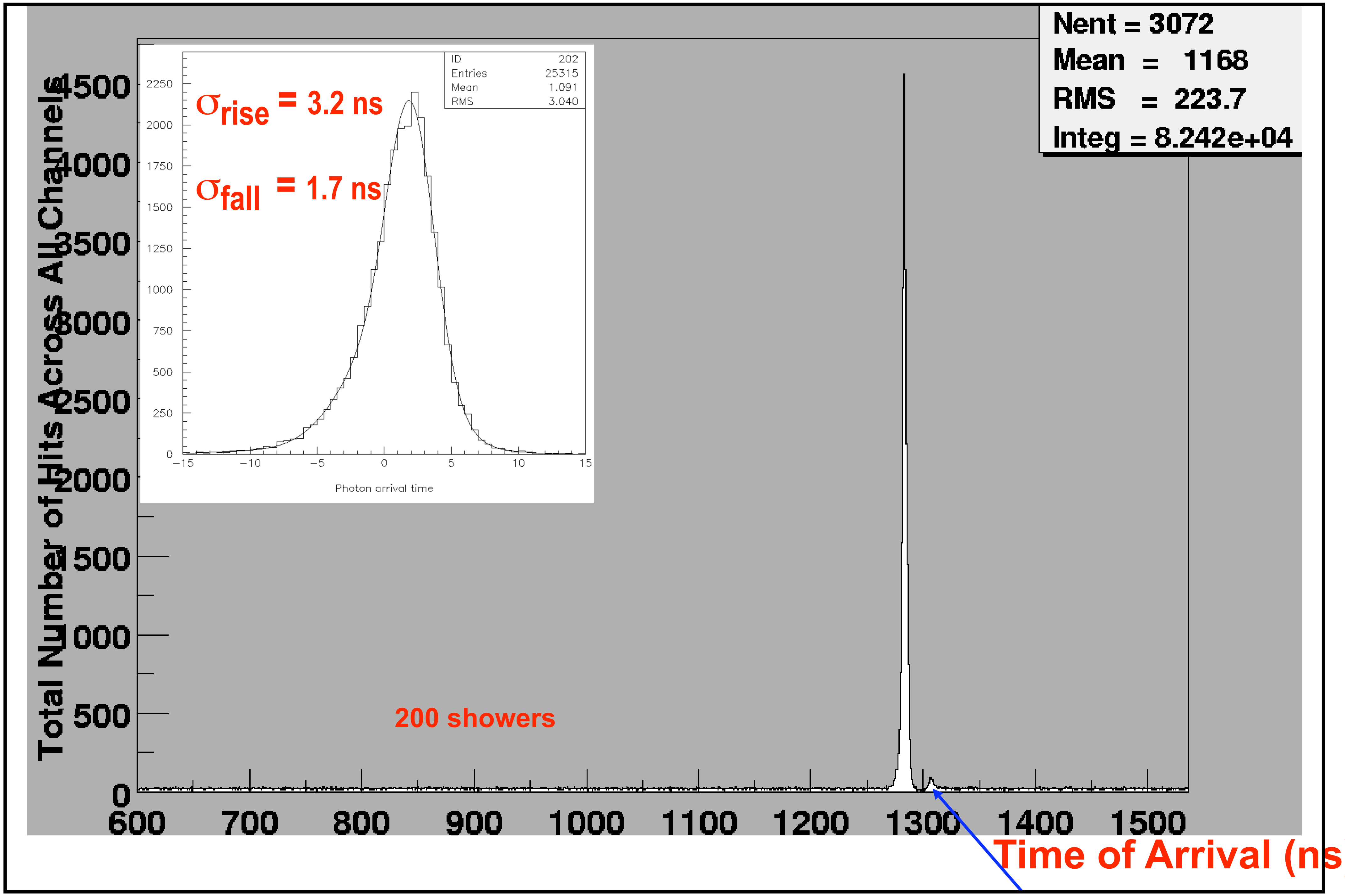
*limited by aperture

CACTUS is capable of collecting nearly the entire Cherenkov light pool



CACTUS Timing Resolution

Data are recorded in multi-hit TDCs with a time-of-arrival resolution of 0.5 ns.
S/N for Cherenkov wavefront detection is excellent.

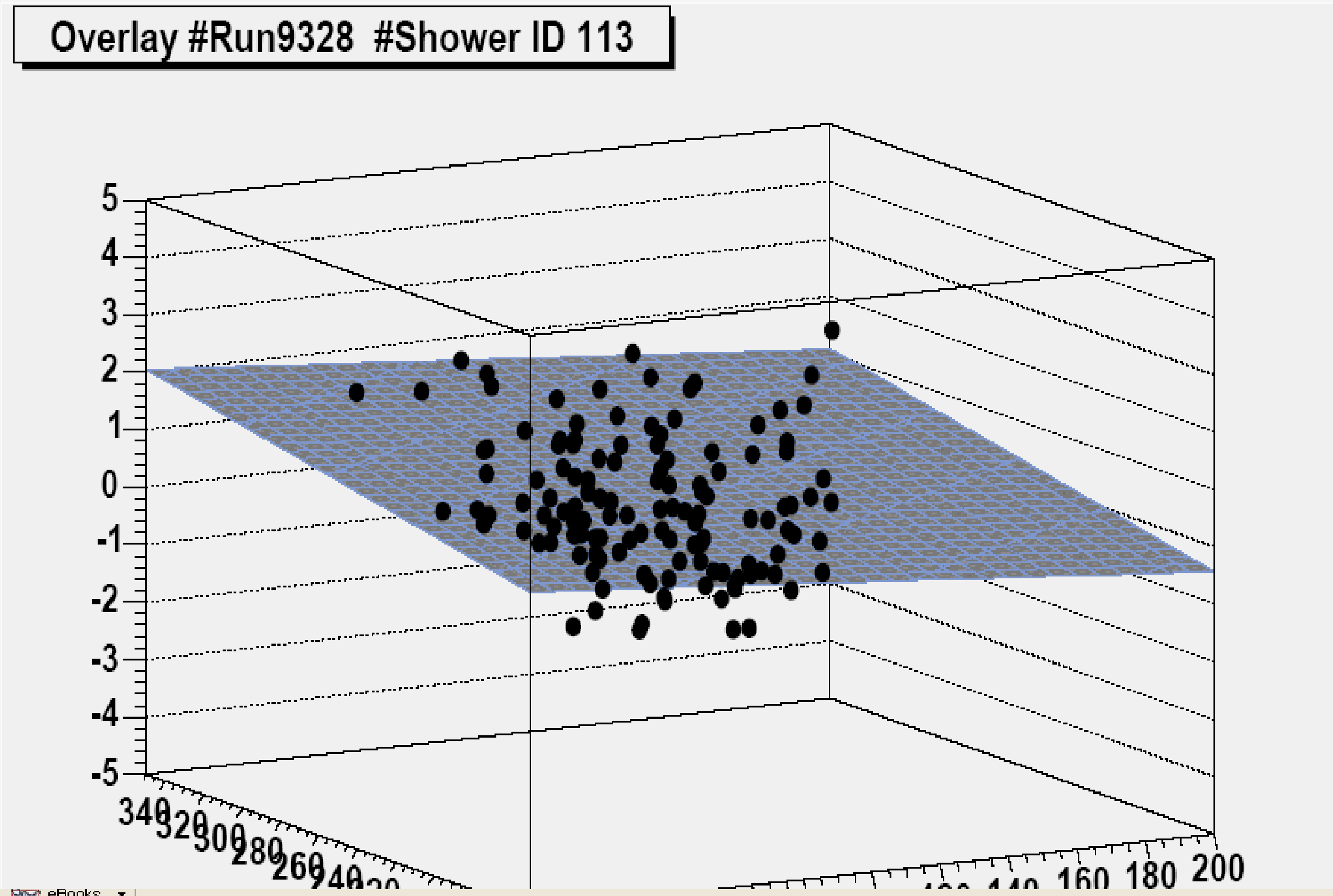


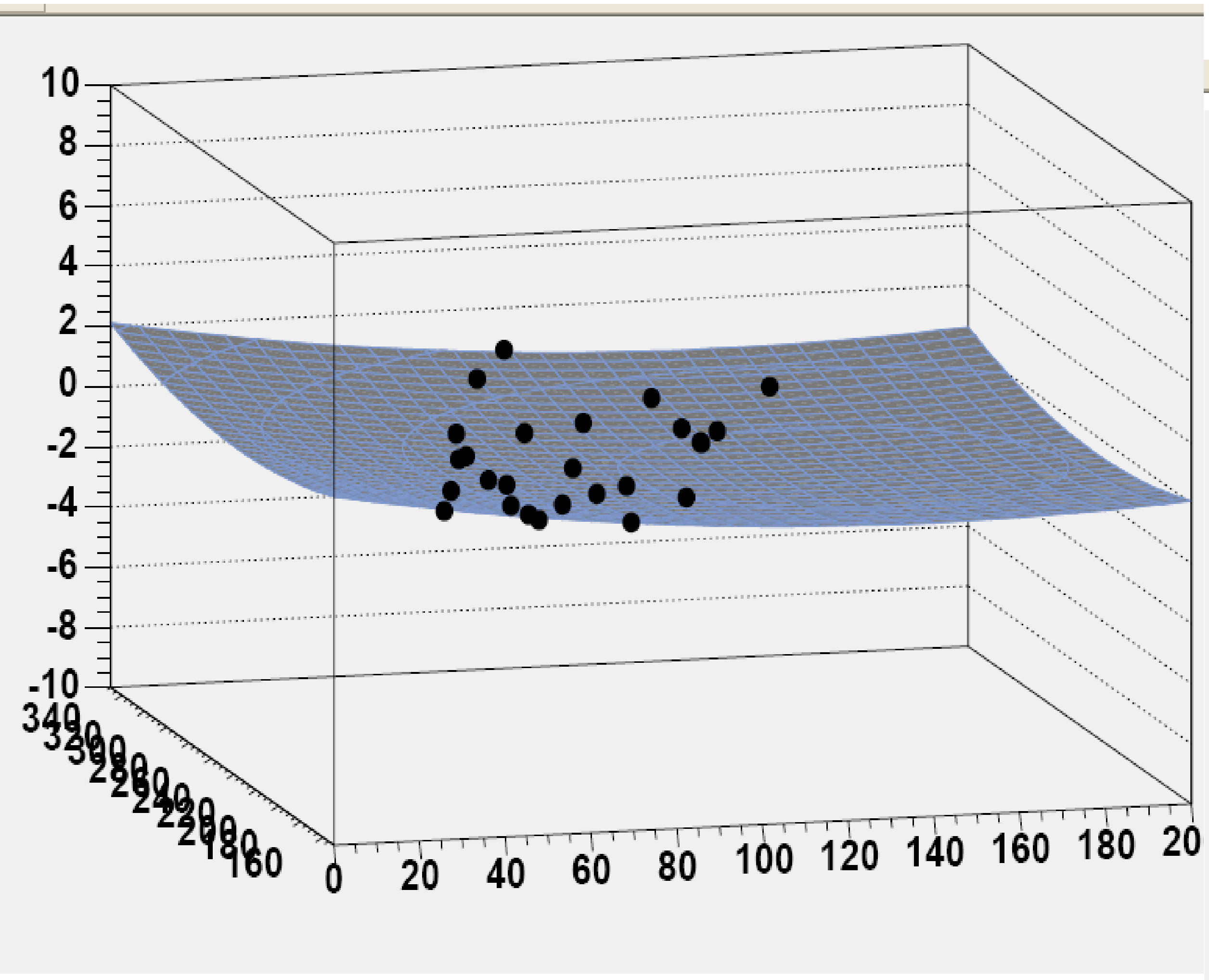
Early plot from ~2002 when using only 32 heliostats. The small bump after the main peak led us to consider the technique of multiple mapping of heliostats.

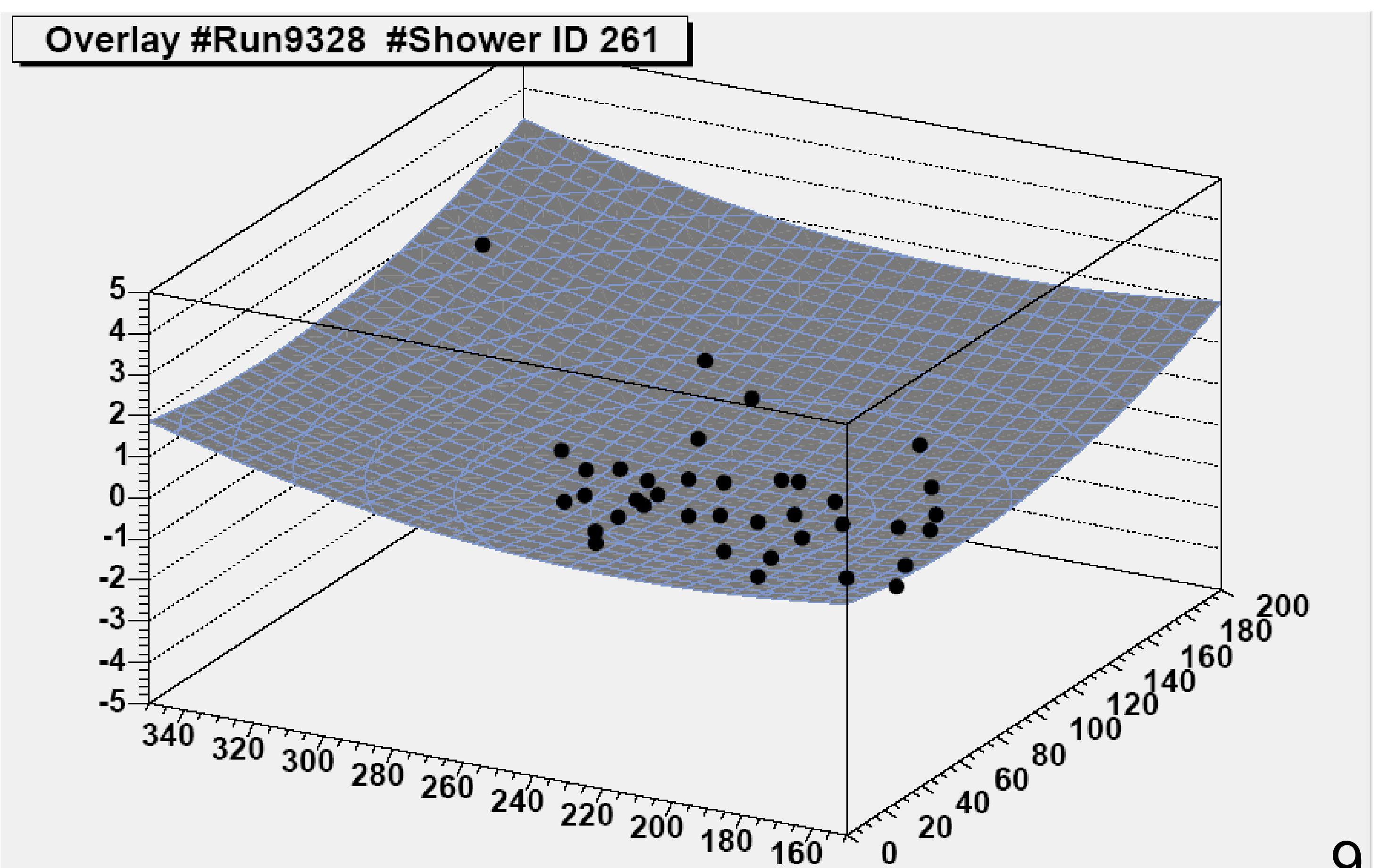
Event Shape Analysis

Typical events with fitted wavefront overlaid on hits.

(work in progress)

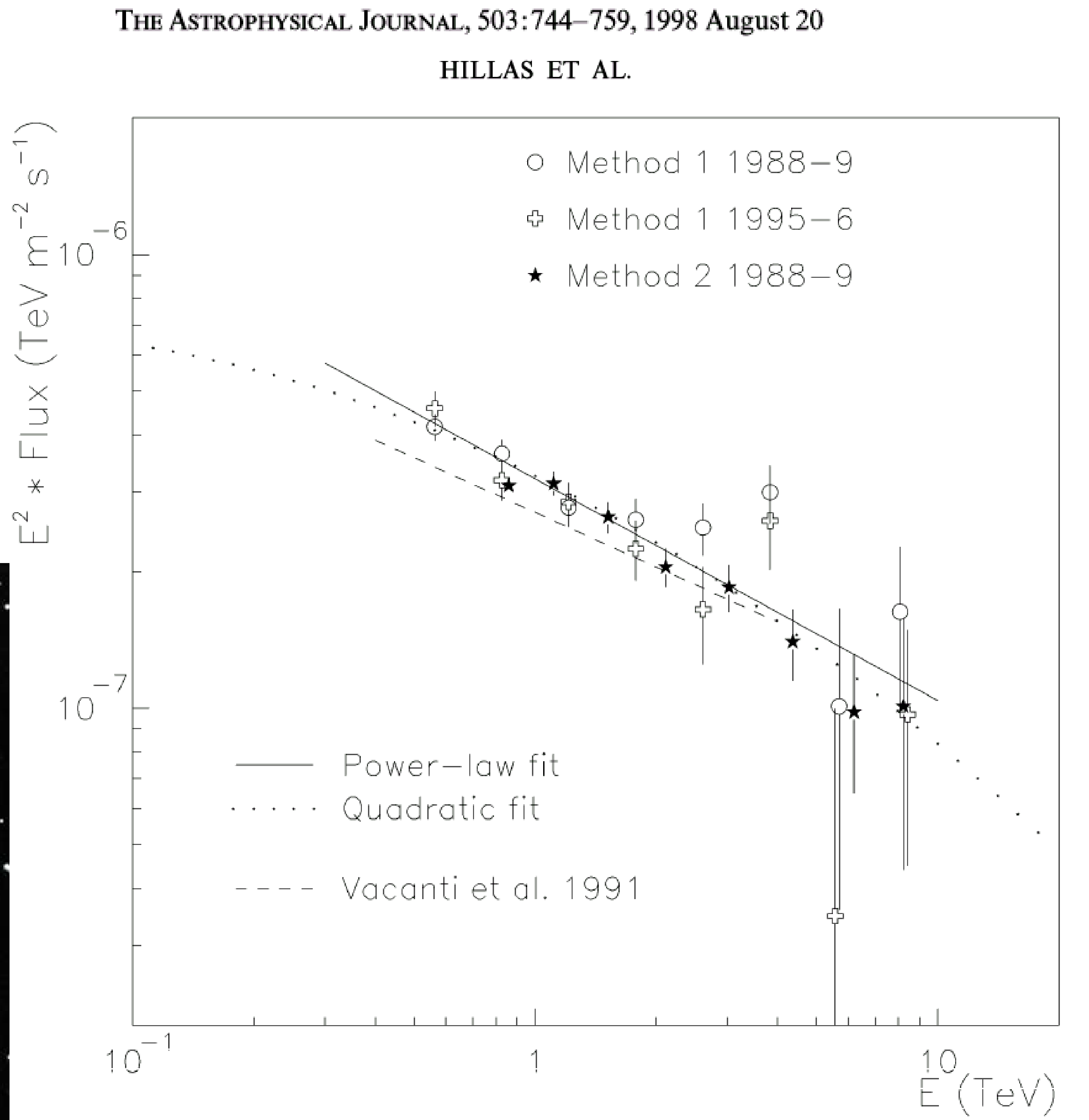






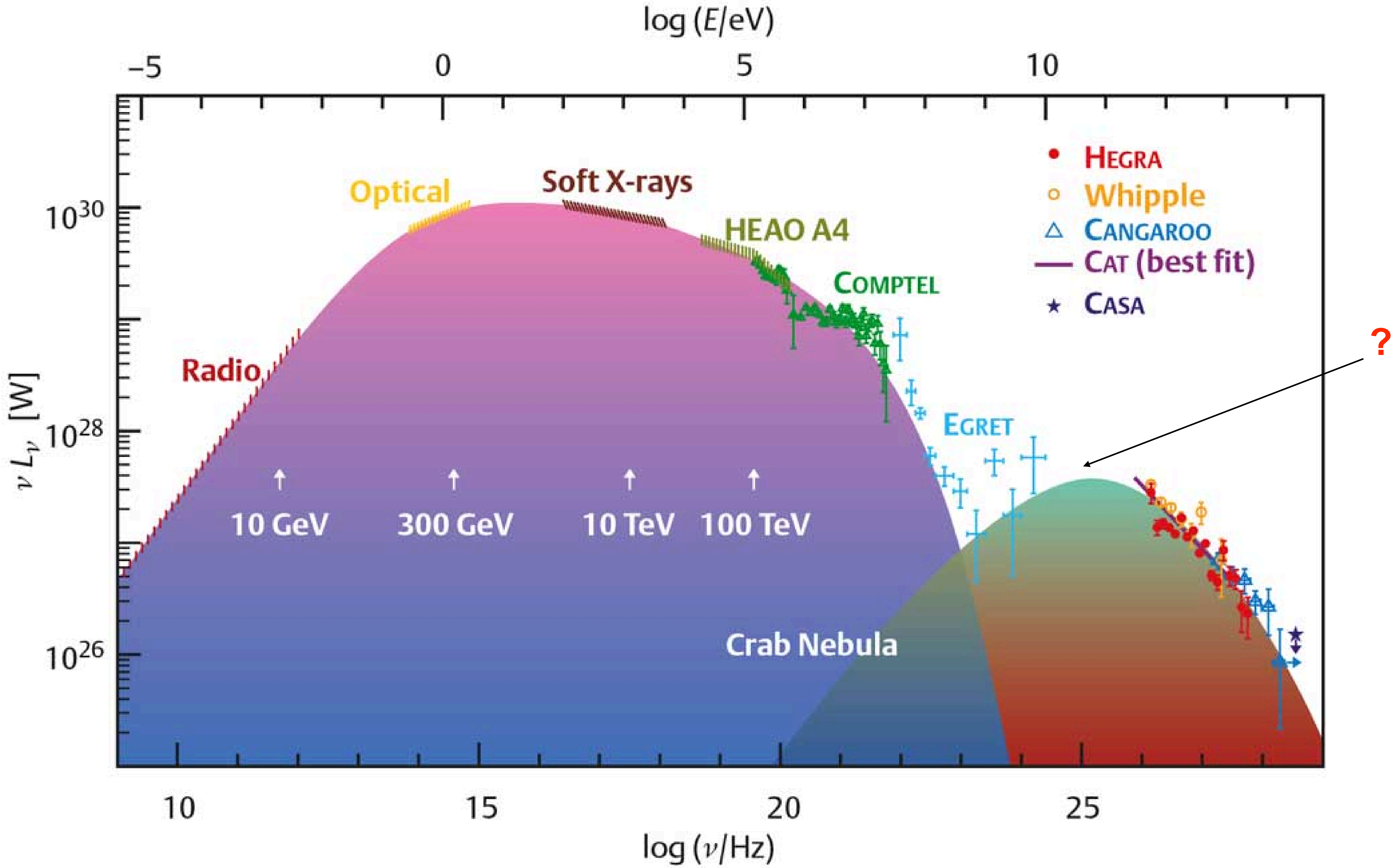
Calibrations using Crab Nebula

The <u>standard candle</u> of gamma-ray astrophysics, the Crab has been studied extensively and is now believed to have a well known and stable spectrum above ~200 GeV.



Crab Spectrum

Crab spectrum has not been established in the 10-100 GeV region, thus making it difficult to use as a standard candle in this regime. Must rely on simulations and our own measurements.



CACTUS Total Pulse-Height Crab Excess

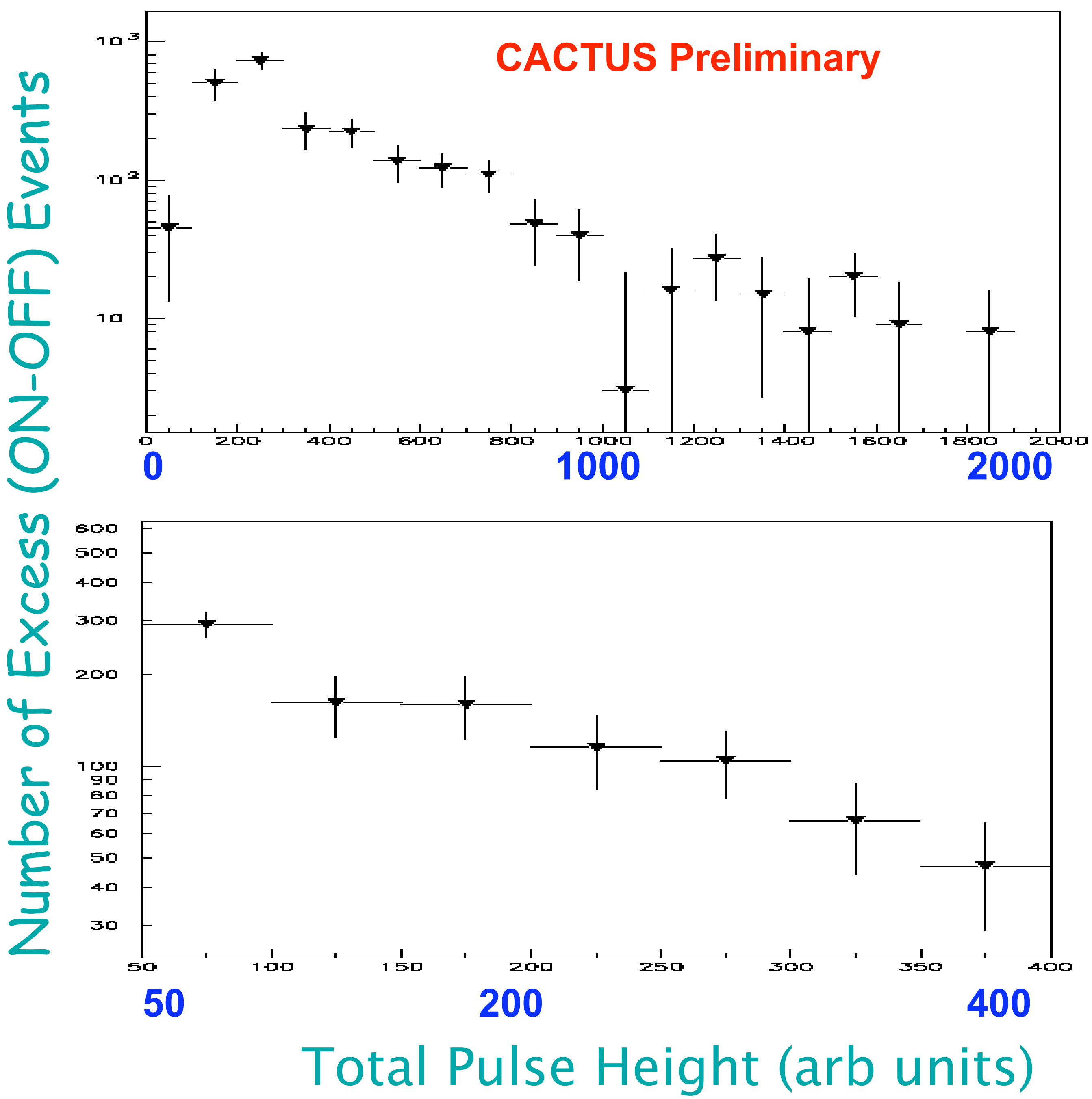
ON-source: heliostats track the Crab for 30 minutes
OFF-source: heliostats track a point 0.5 degree away from the Crab for 30 minutes.

We require >7 channels in a 13 ns window for the event to be triggered.

This 28 min sample from the Crab represents an excess rate of 42/min. The significance of this detection of Crab in 28 mins is 13 σ

The horizontal scale is “total measured pulse height” which is closely related to the incoming energy. The lower plot is re-binned data in the 50-400 range.

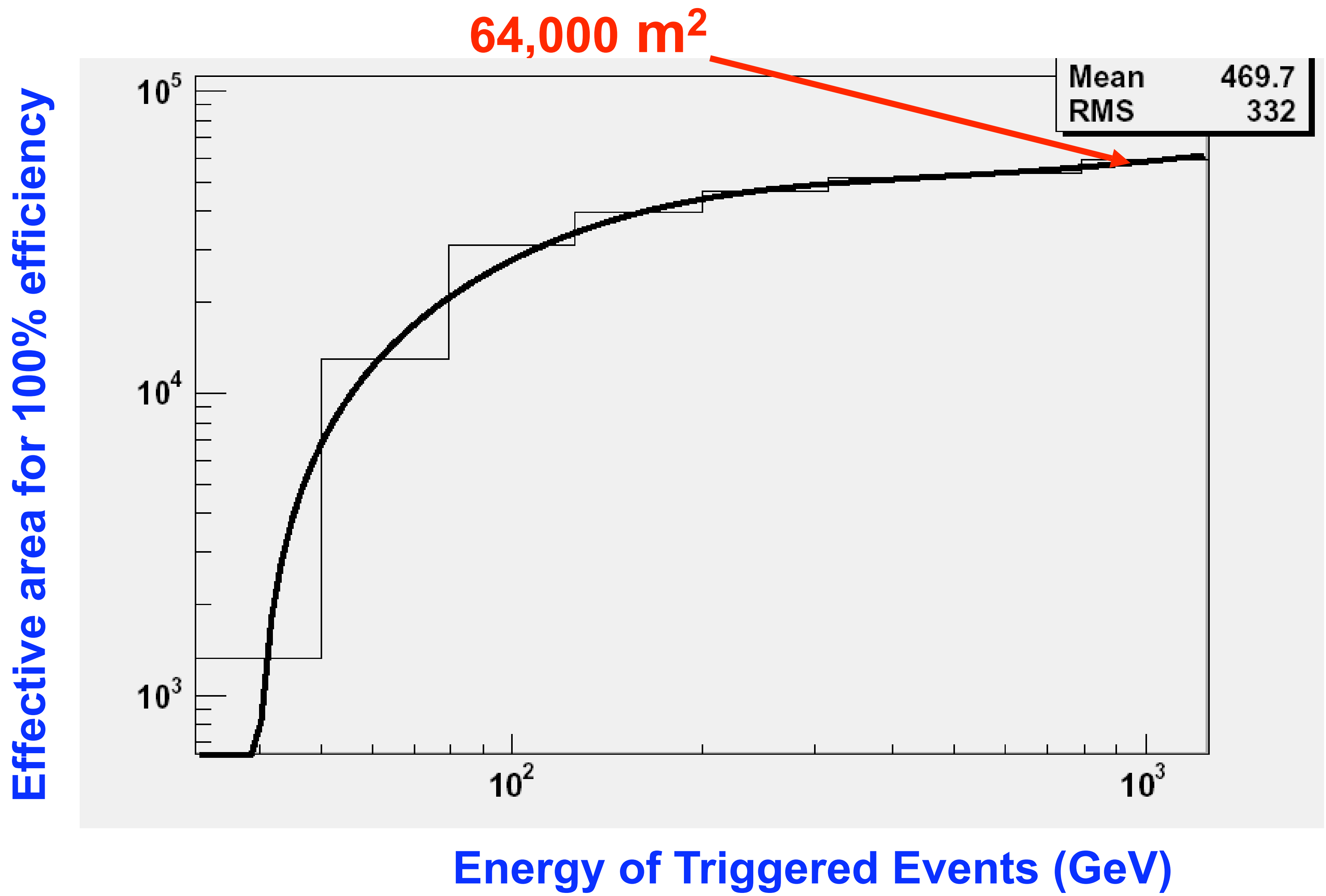
The range of measurements here represent an energy range of ~ 50-1000 GeV.



Efficiency and Effective Area

Events generated spread uniformly over a radius of 180 m with input spectrum of $k*E^{-2.4}$

Simulations indicate an effective area >50,000 m^2 for energy > ~200 GeV.



$$A_{effective} = 47{,}000x[1 - e^{-0.014x(Energy-39.6)}] + 11.9xEnergy$$

Recent Crab Measurements

MAGIC has made measurements of the Crab with a long lever arm in energy.

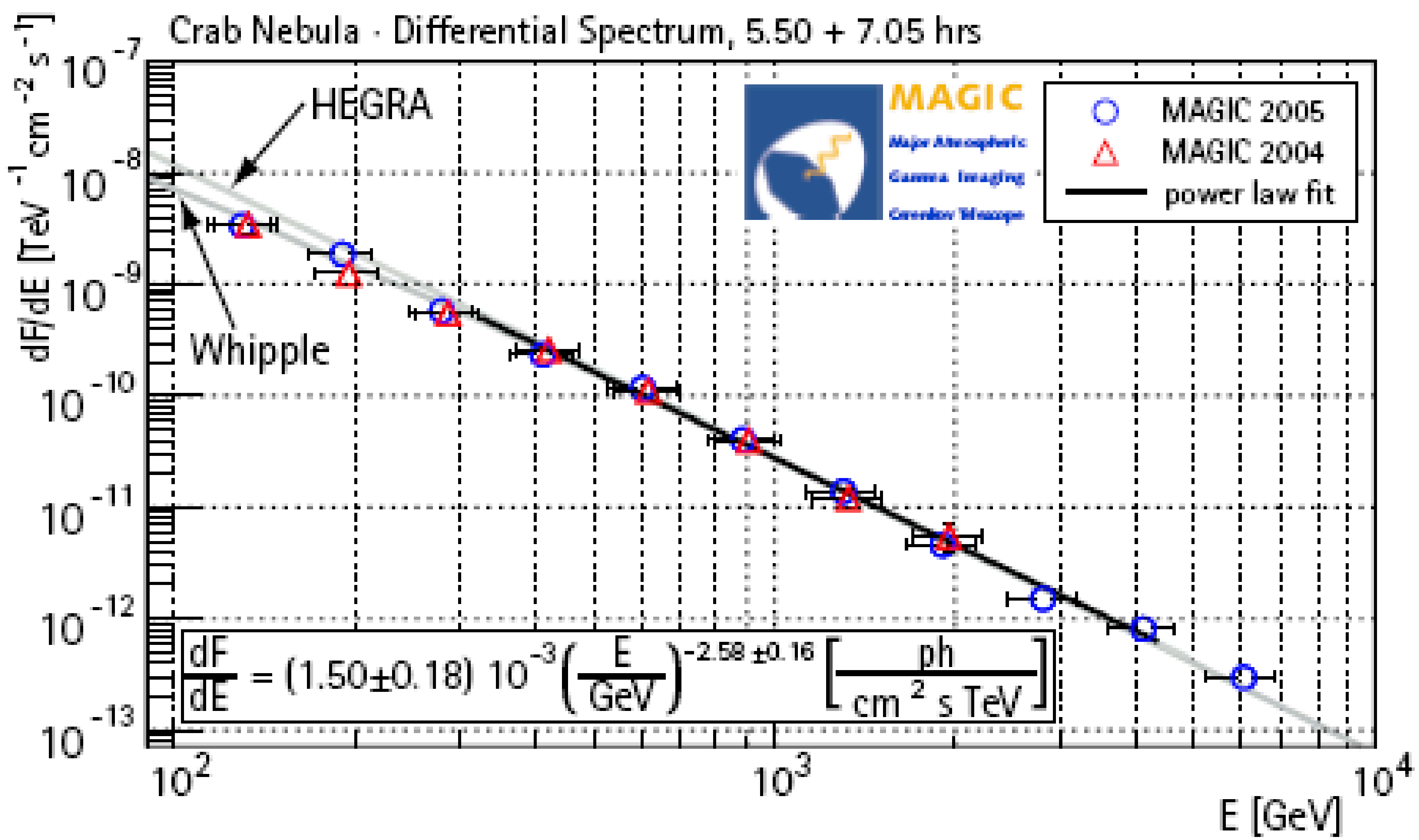
The lowest data point is at ~130 GeV with a flux of ~5x10^{-8} GeV^{-1} m^{-2} s^{-1}.

This is a good calibration point for comparing CACTUS with MAGIC.

29th International Cosmic Ray Conference Pune (2005) **00**, 101–106

Observations of the Crab nebula with the MAGIC telescope

R. M. Wagner[a], M. Lopez[b], K. Mase[a,f], E. Domingo–Santamaria[c], F. Goebel[a], J. Flix[c], P. Majumdar[a], D.Mazin[b], A. Moralejo[d], D. Paneque[a], J. Rico[c], and T. Schweizer[e]
on behalf of the MAGIC collaboration



CACTUS Measurement of Crab Spectrum

CACTUS Fit

$dF/dE \sim 0.019 \times E^{-2.64}$

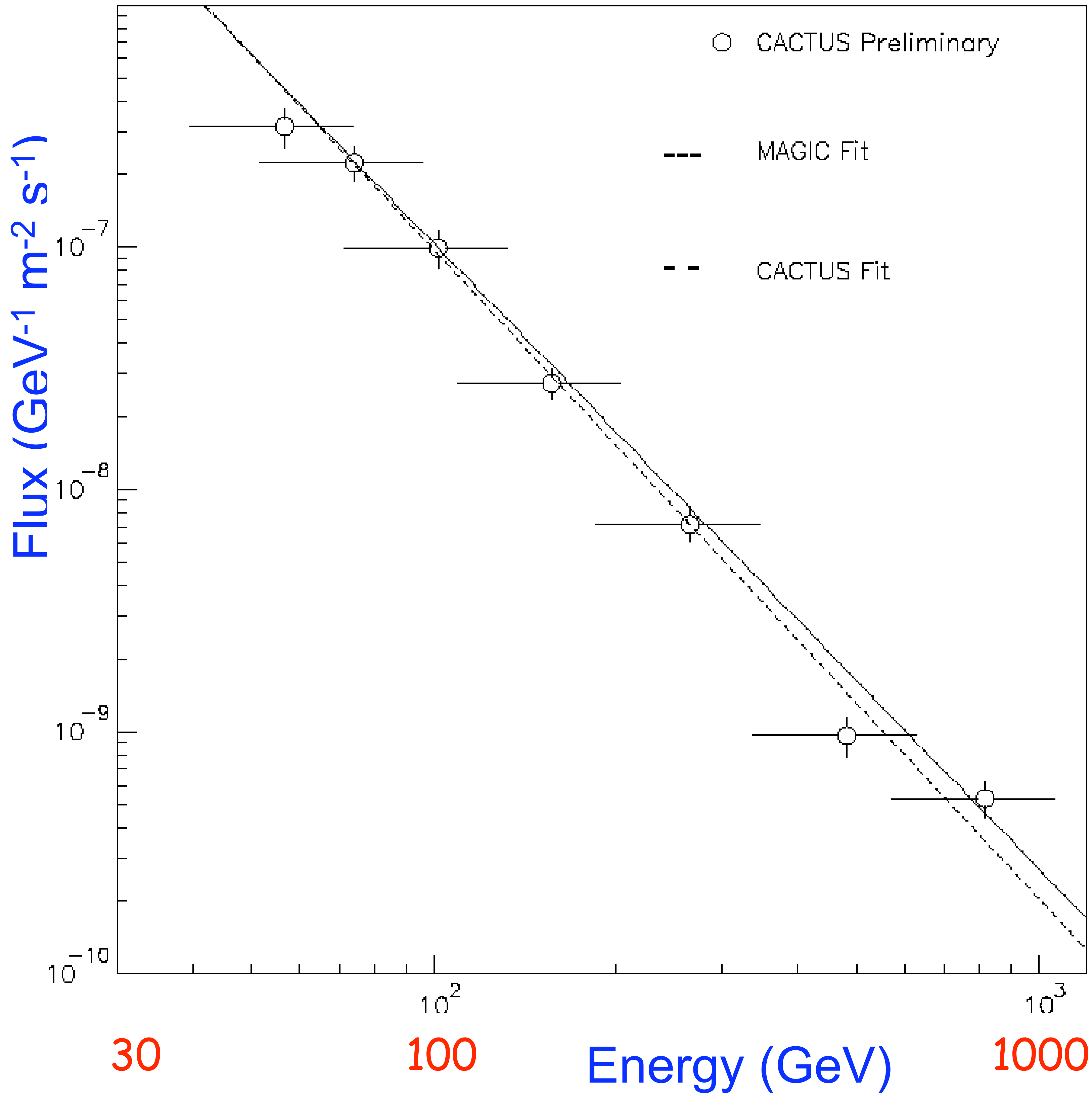
$(GeV^{-1}\ m^{-2}\ s^{-1})$

Errors are dominated by systematics:

~30% in Energy

~10% in Flux due to simulation error in effective area determination

Point at 55 GeV is below the fit. The flux at higher energies is in good agreement with an extrapolation of the MAGIC fit.

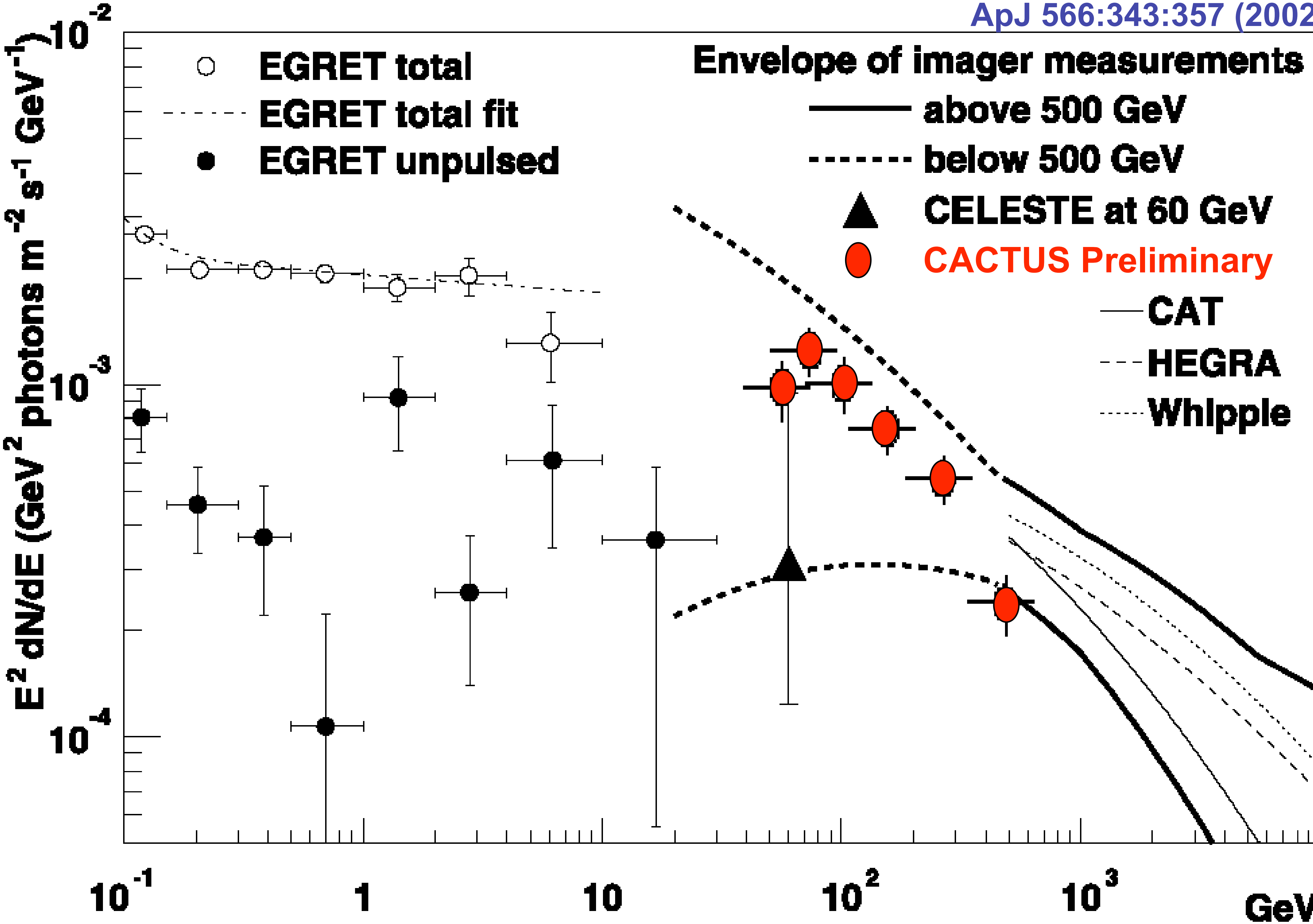


Integrated Flux at Low Energies

MEASUREMENT OF THE CRAB FLUX ABOVE 60 GeV WITH THE CELESTE CERENKOV TELESCOPE

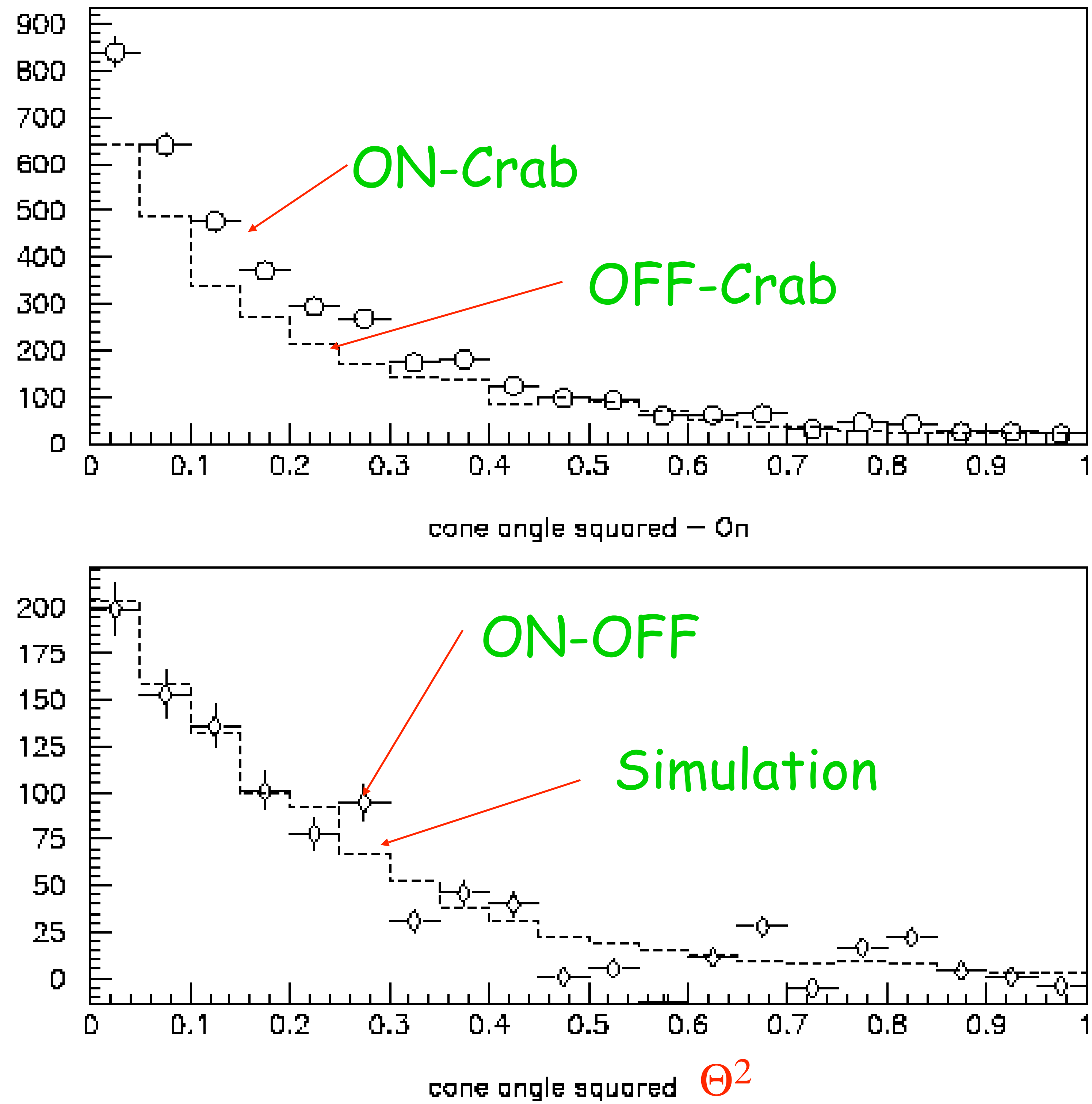
M. de Naurois,[1,2] J. Holder,[3,4] R. Bazer-Bachi,[5] H. Bergeret,[3] P. Bruel,[1] A. Cordier,[3] G. Debiais,[6] J.-P. Dezalay,[5]
D. Dumora,[7] E. Durand,[7] P. Eschstruth,[3] P. Espigat,[8] B. Fabre,[6] P. Fleury,[1] N. Hérault,[3,6] M. Hrabovsky,[9]
ʀannot,[7,12]
ᴠolte[8]

ApJ 566:343:357 (2002)



Angular Resolution for the Crab

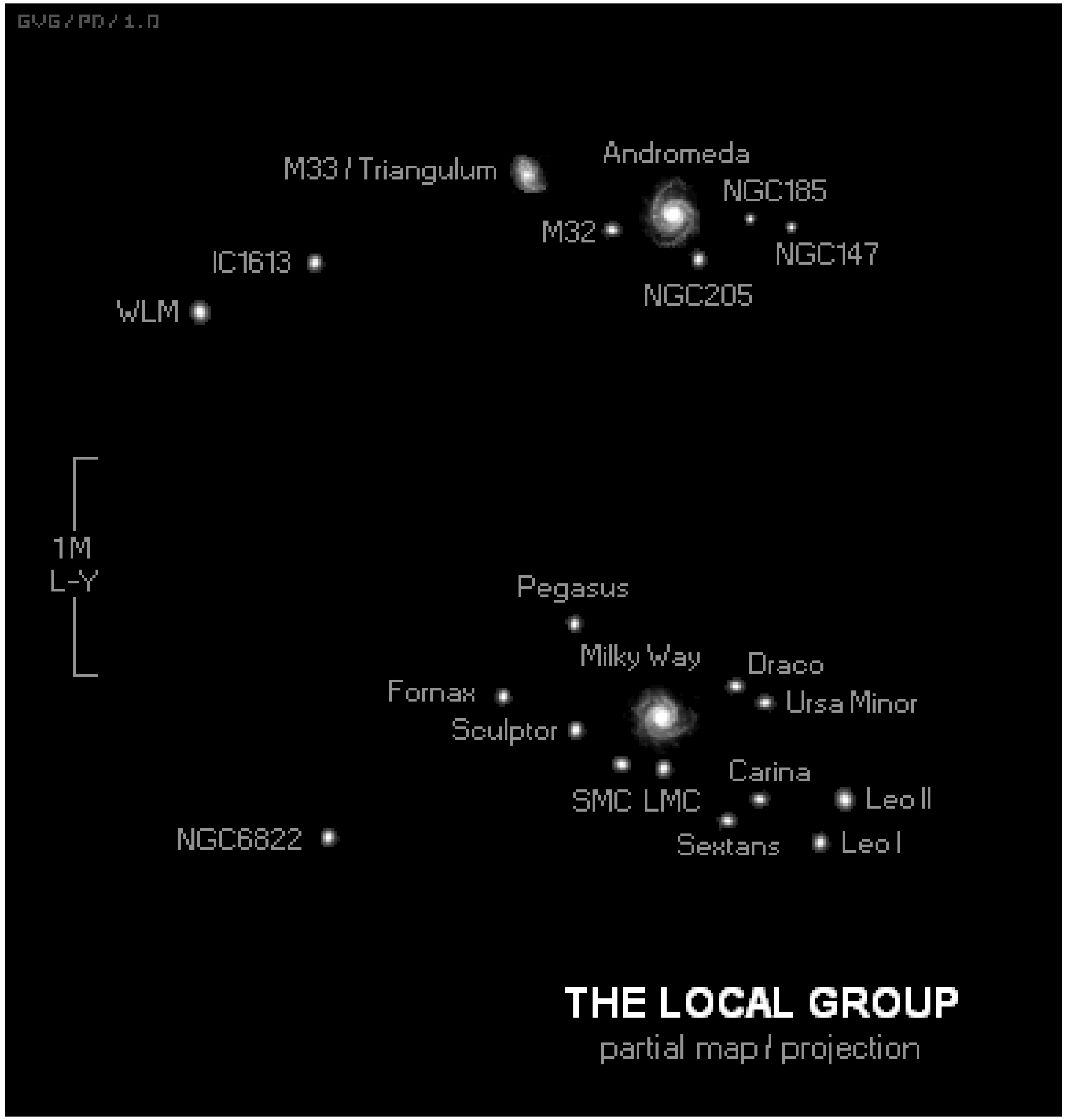
A planar fit to the shower wavefront yields an angle for the direction of the incoming gamma ray. The Crab is a point source and our excess is peaked at zero cone-angle. Simulations reproduce the shape measured in the data.



The resolution in Θ^2 is ~0.2 degrees. We hope to improve this with improvements in the fitting technique.

Draco and Dark Matter

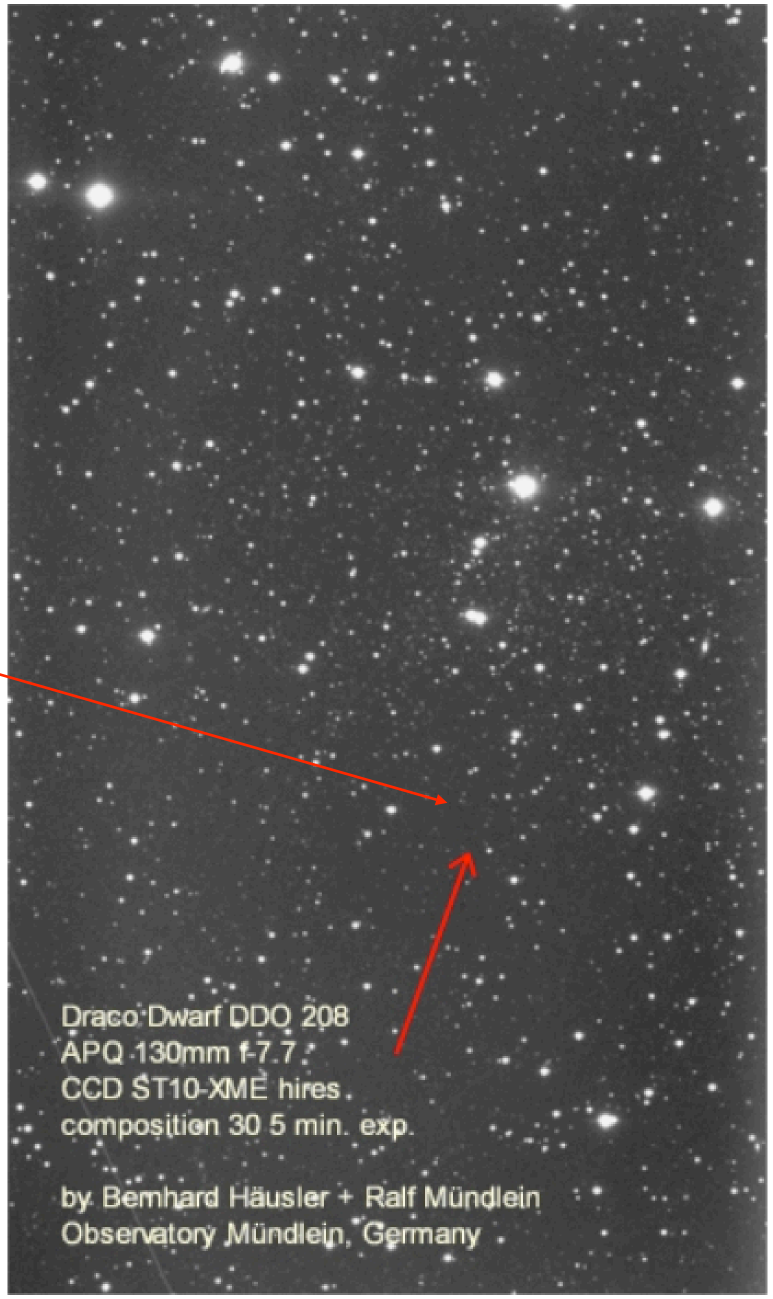
Draco is a dwarf spheroidal galaxy in the vicinity of the Milky Way. Estimated total mass ~0.3 - 8 x $10^7 M_{solar}$. Draco has low luminosity of ~2 x 10^5 L_{solar}, so global mass-to-light ratio in the 15-400 range. Requires that Draco contain a dominant (93-99%) dark matter component.



Draco is ~0.5 degrees across.

Very faint in the optical.

Integrated magnitude ~11 making it an ideal candidate for ACT observations.



Neutralinos: Attempt at understanding Draco

Neutralinos are generally the lowest mass superpartners in Minimal SUSY Models.

Colorless, neutral and stable, they are a popular candidate for Cold Dark Matter.

Neutralinos can annihilate into quark and anti-quark pairs. Resulting hadron jets will contain gammas from neutral pion decays.

Annihilation rate depends on ρ^2, where $\rho \sim r^{-\gamma}$ is the density profile of neutralinos.

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Particle dark matter constraints from the Draco dwarf galaxy

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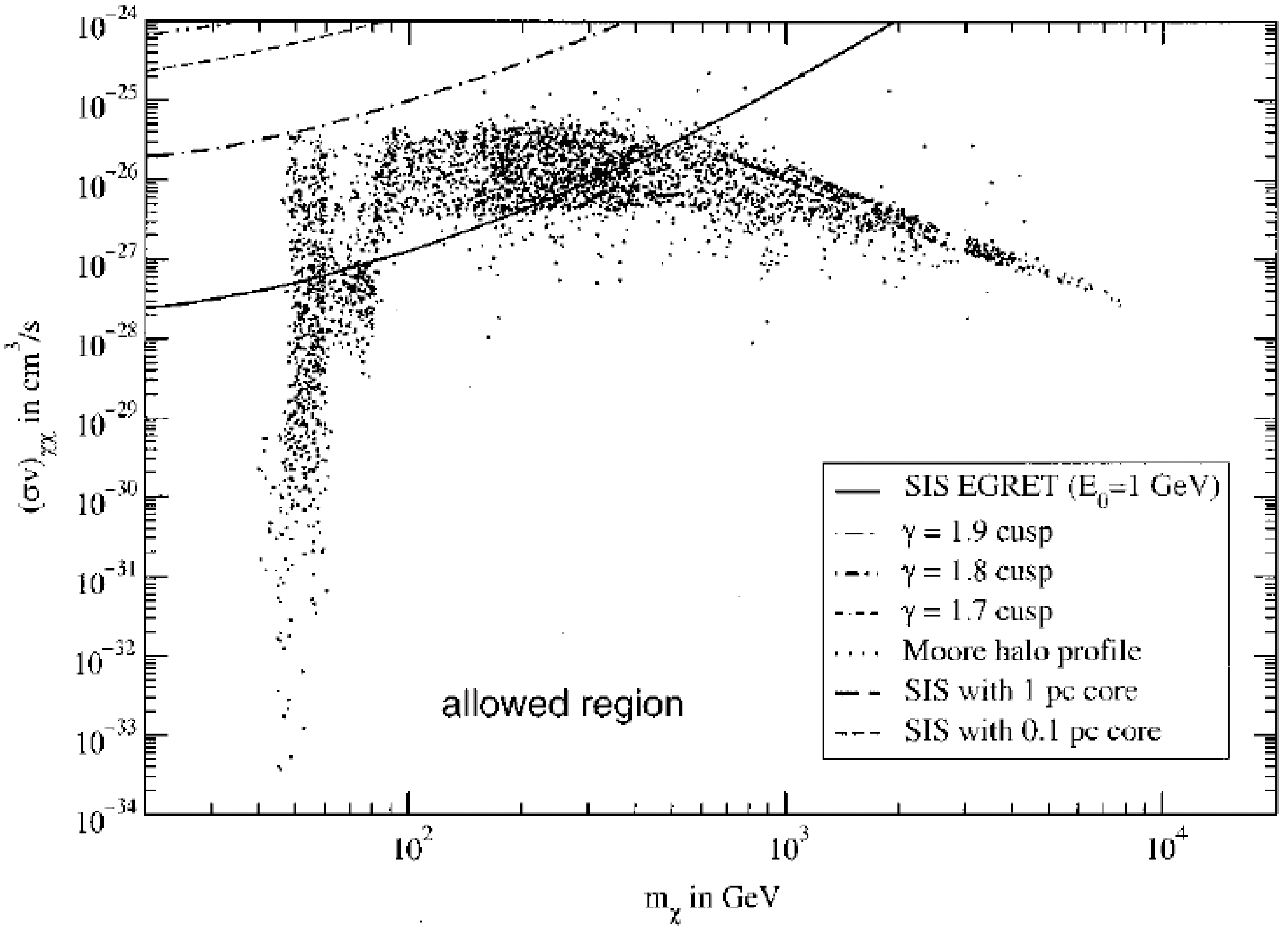
(Received 18 March 2002; published 3 July 2002)



CACTUS Reach for Draco

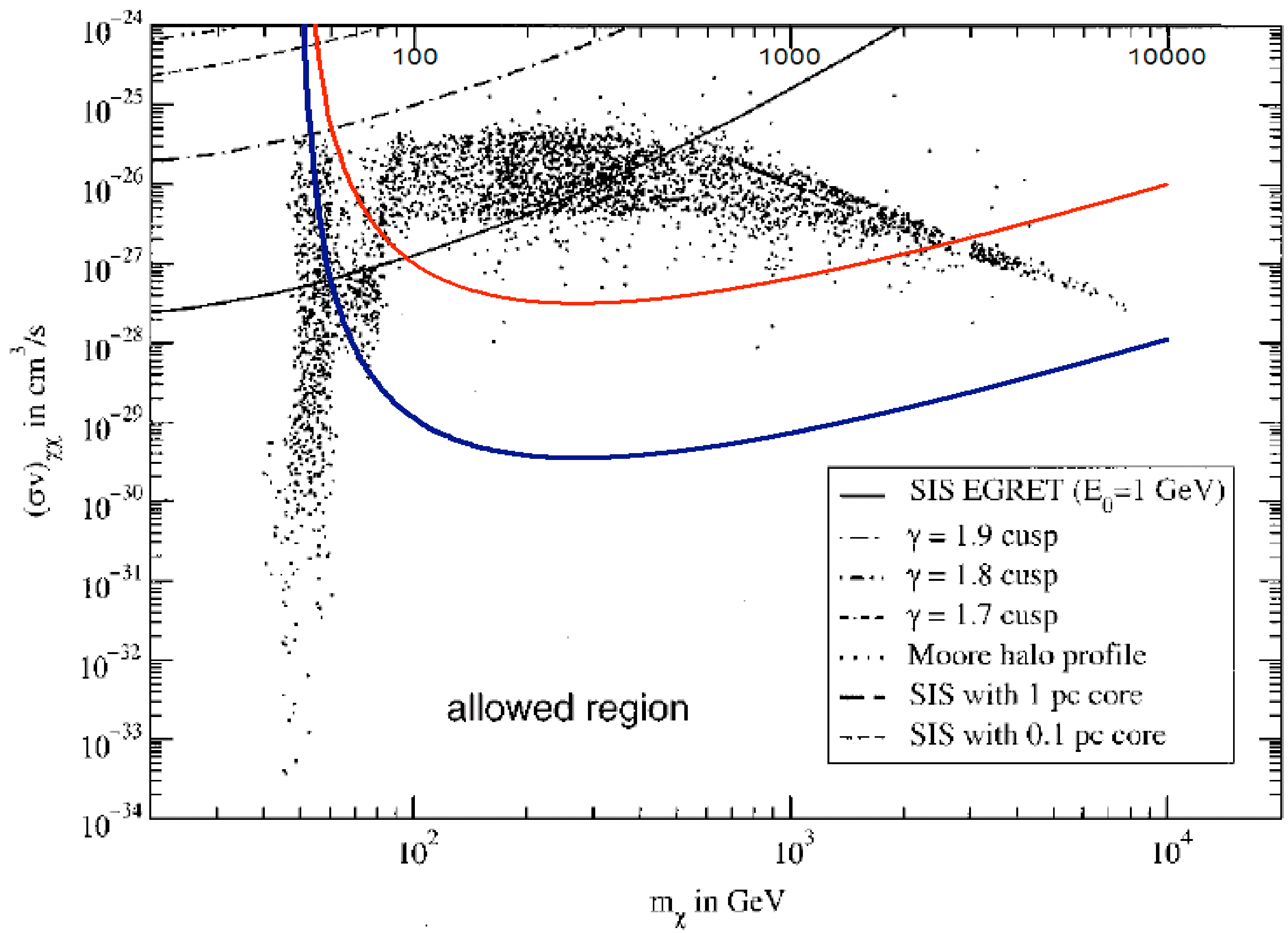
SUSY Parameter Space Probed by CACTUS

-Effective Area = 20, 000 m^2 -Energy Threshold = 50GeV -7 hrs of observation

- Red curve indicates detection of a signal with 5 sigma significance for a SIS with a 1 au core and 5 Hz background rate.

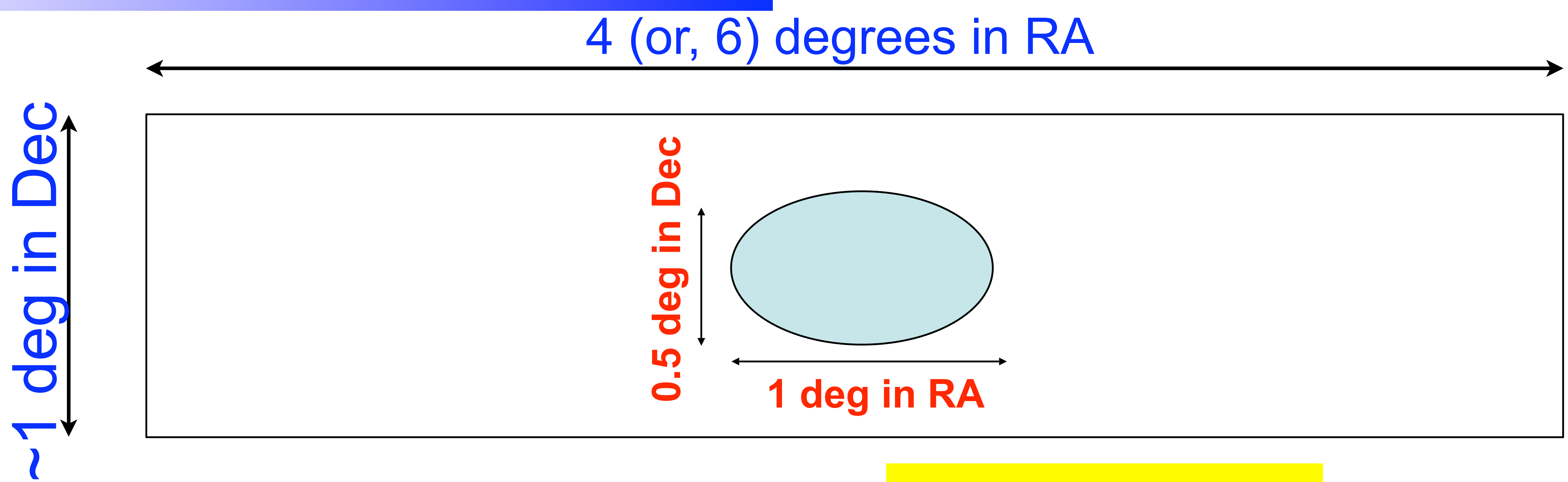
-Blue curve indicates detection of a signal with 5 sigma significance for a modified SIS with a 1 au core and 5 Hz background rate.

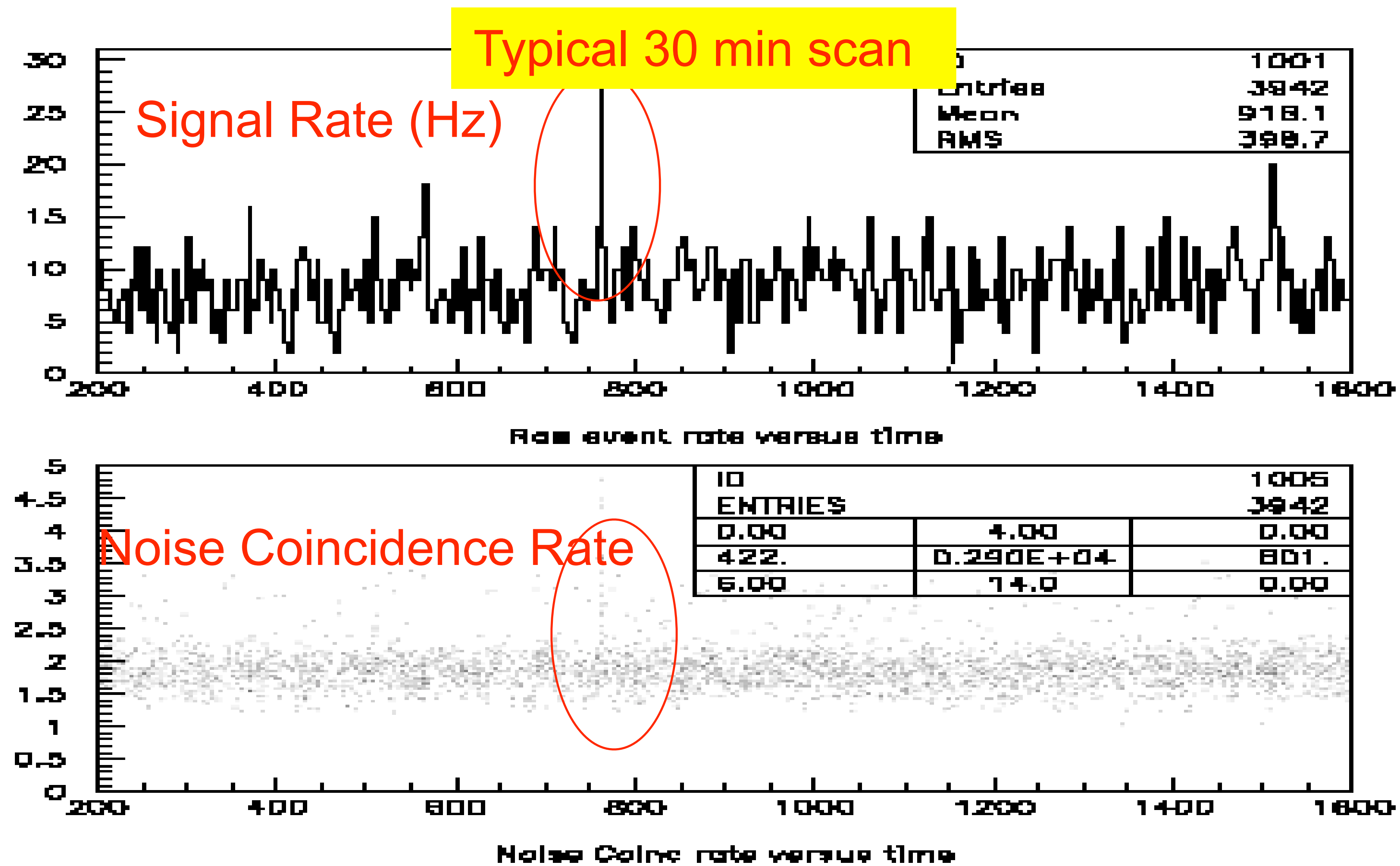
Modified SIS (singular isothermal shell) makes neutralino profile more cuspy.



Draco Observations

- Drift scans: +- 2 (+-3) degrees in RA.





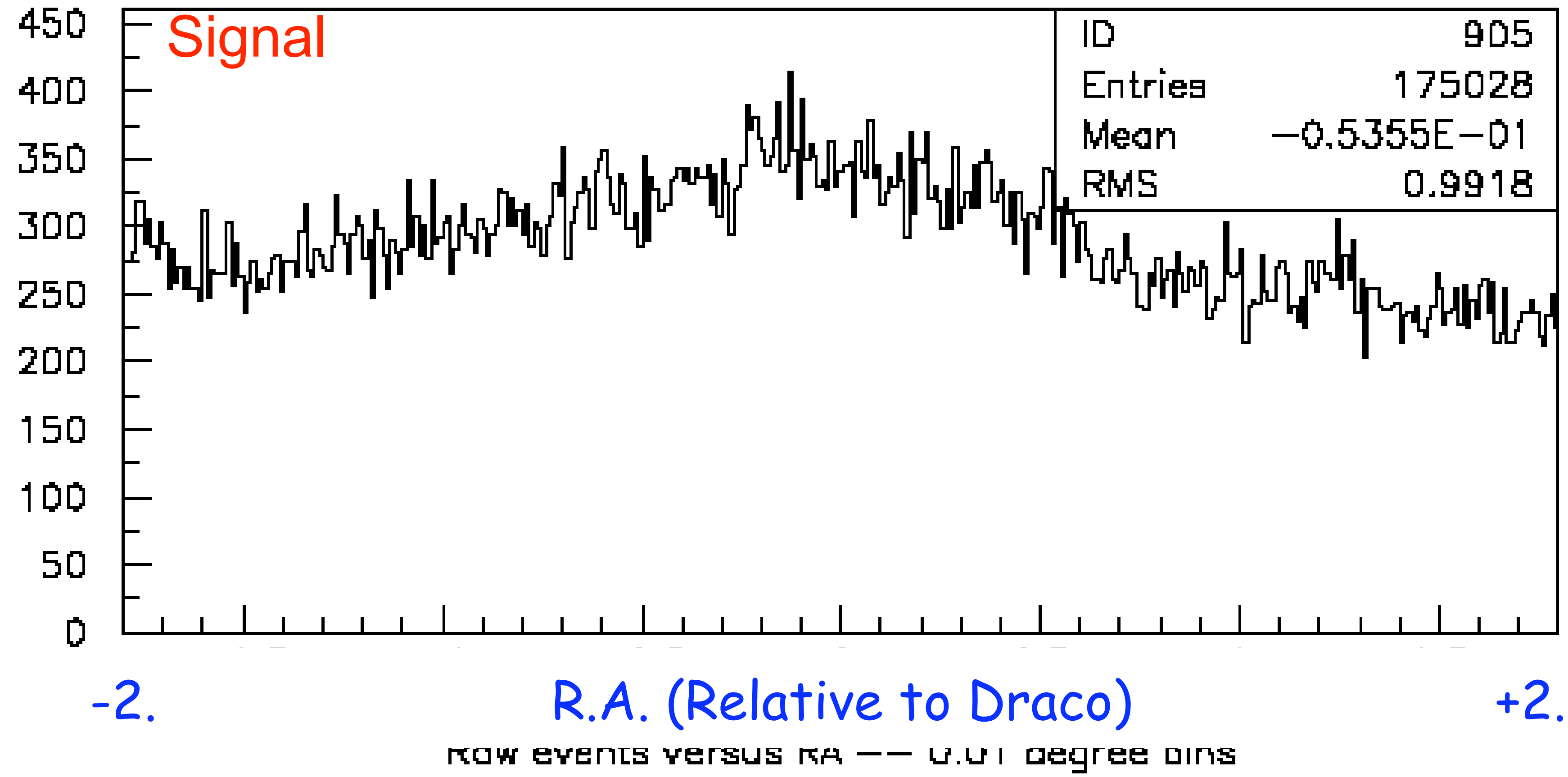
Background noise coincidence rates are recorded for 1 us preceding the triggering event.

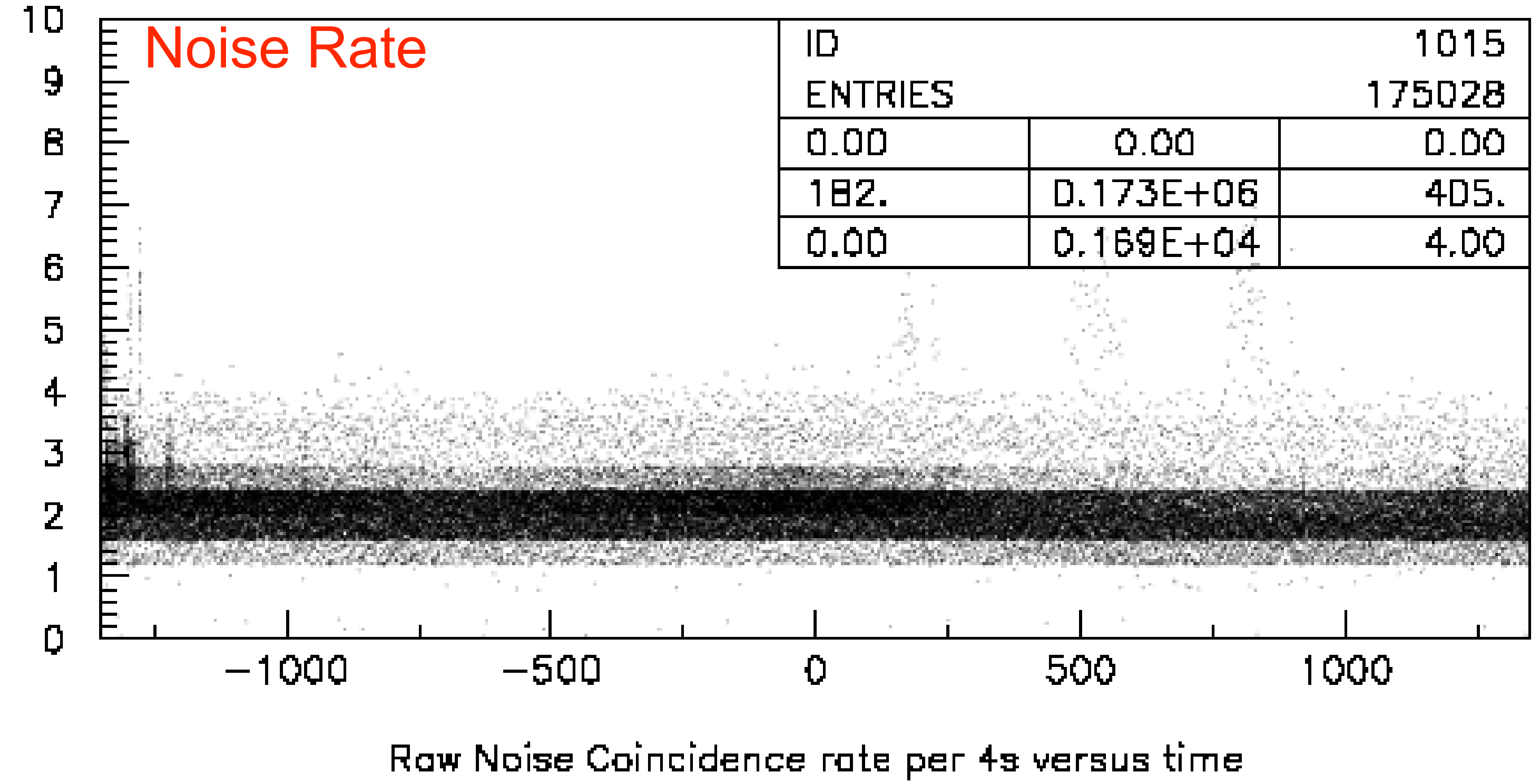
Noise spikes due to fluctuations and/or meteorites, airplanes etc can be tracked in the background noise rate which is otherwise very stable.

Sum of First 7 Draco scans

These data were taken during low background rate conditions.

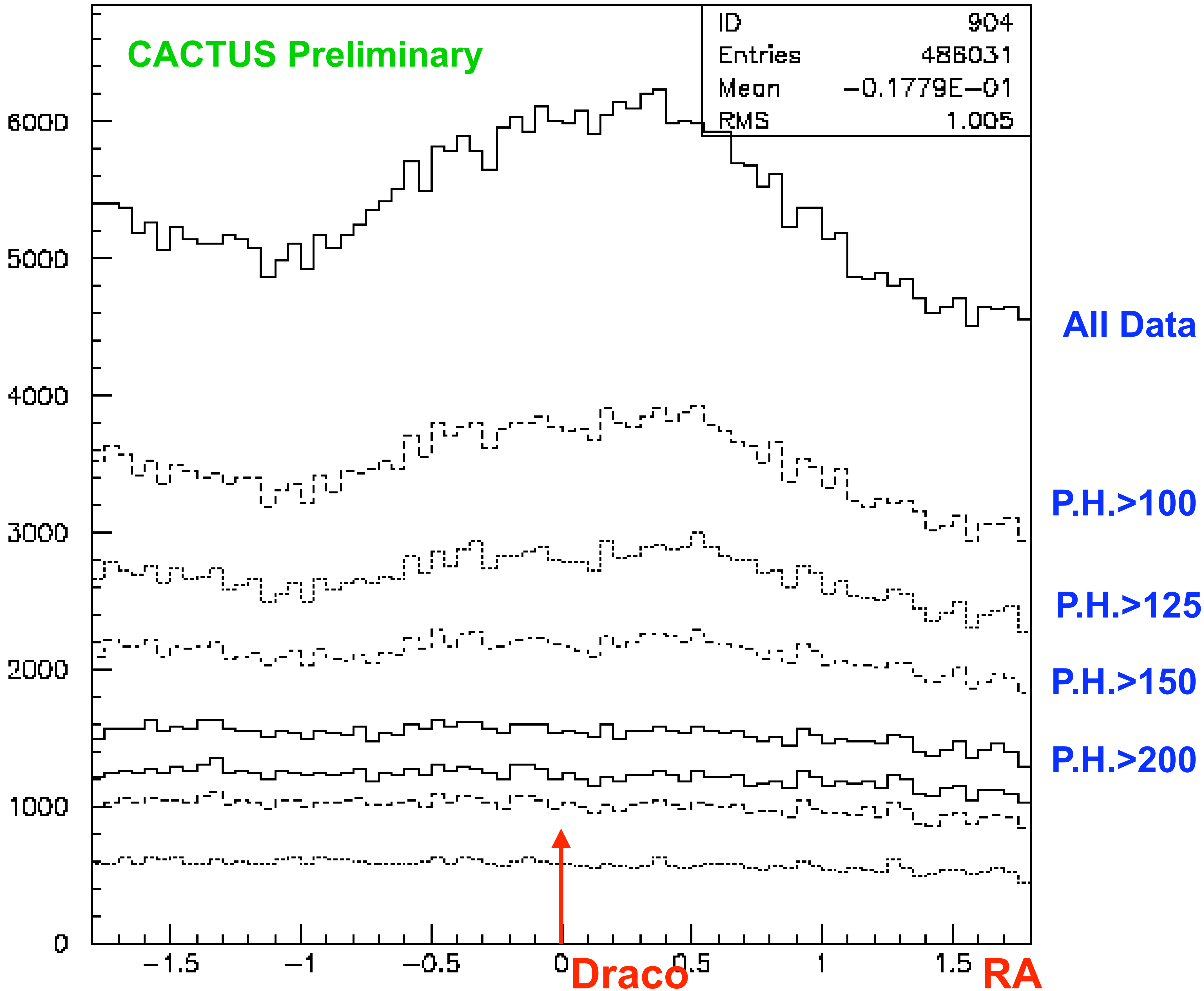
The background is stable, while the scan data show some excess near Draco.





Draco: Integral of 41 scans

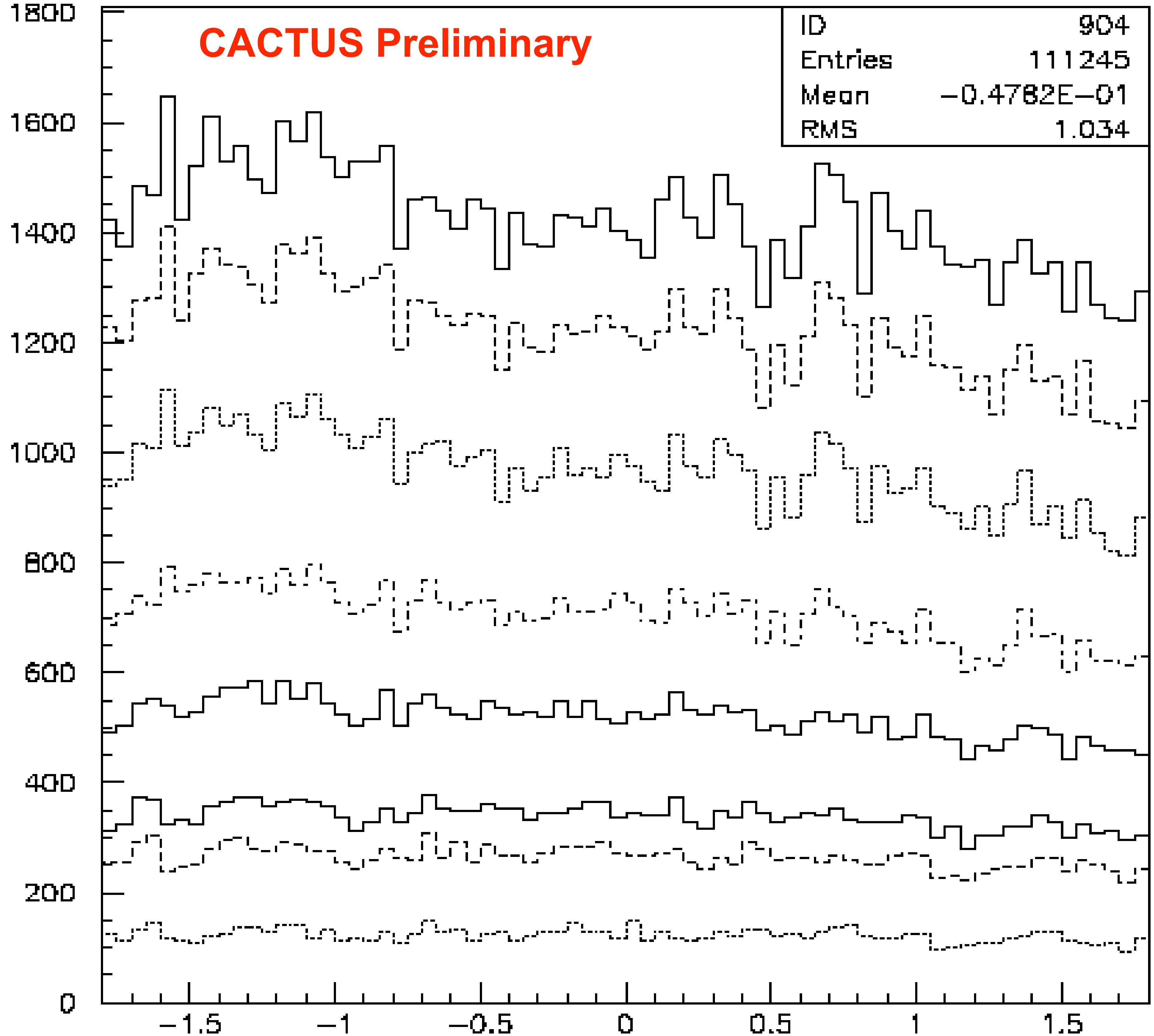
Placing cuts on the total Pulse Height in the event (~energy) reveals that the excess is not visible above about 150, which is ~150 GeV.



Control: Scan of Draco -1 in Dec

A similar set of scans in RA but offset by 1 degree in Dec show flat distributions in all energy bins.

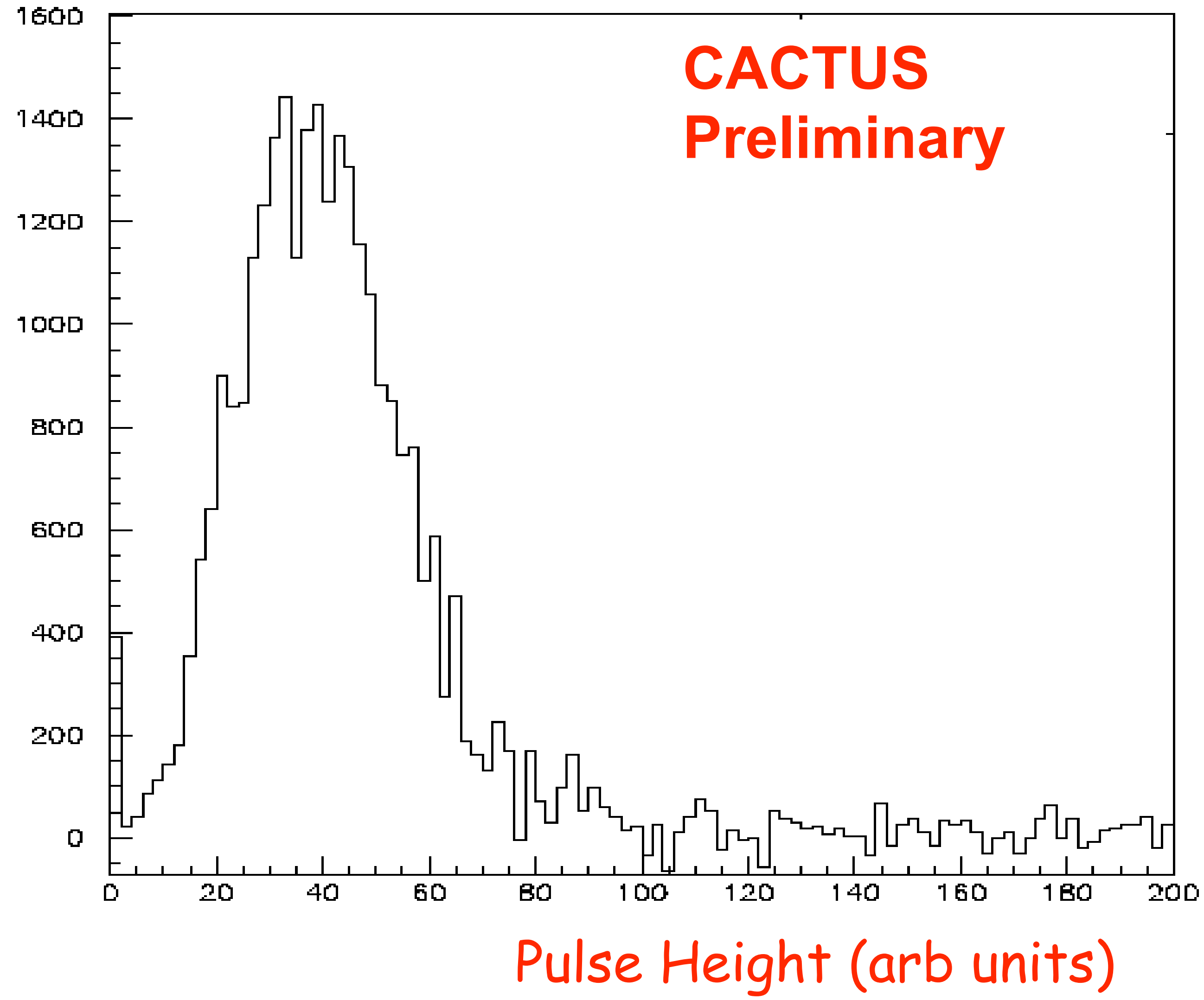
A total of 10 scans are integrated here. The scaled rates agree with the background in 41 Draco scans.



Energy Distribution of Excess

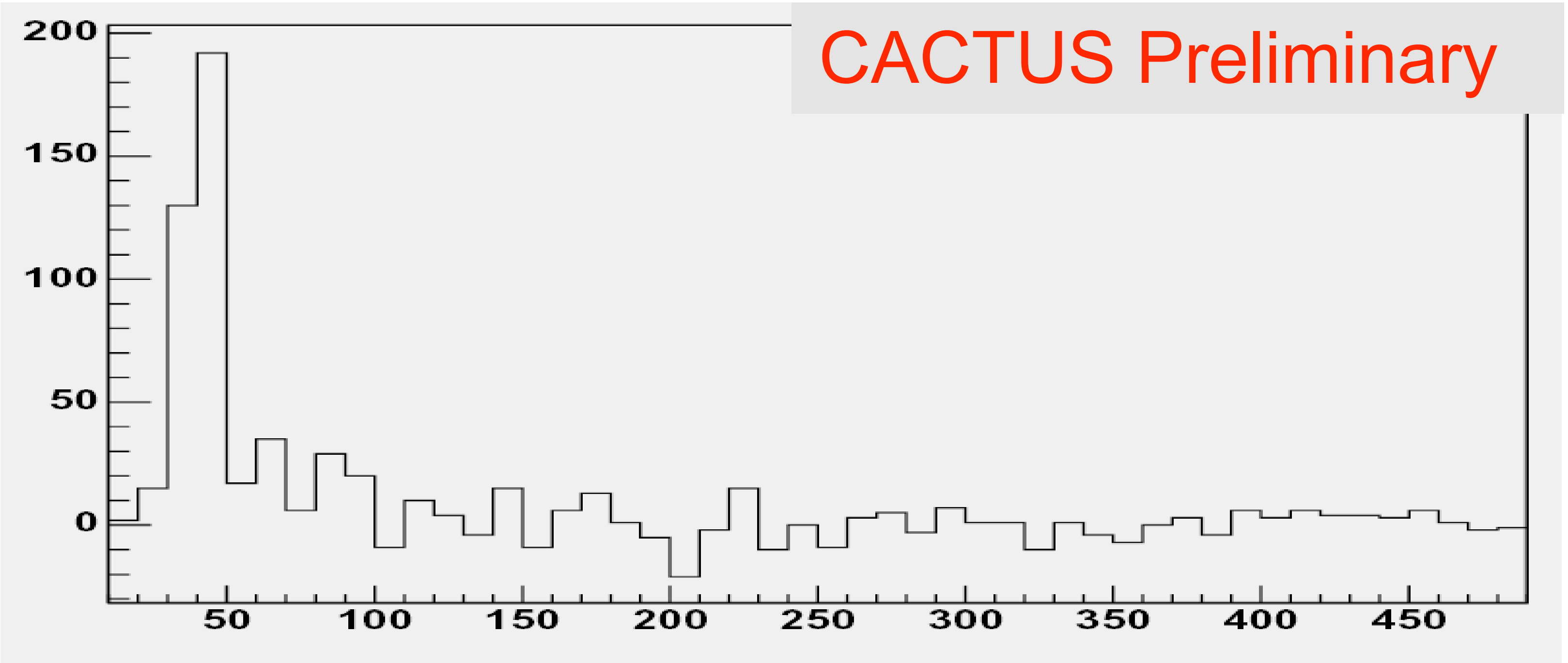
As an estimator of the energy spectrum of the excess in the Draco region, the pulse height distributions in the central region (|RA| < 0.8) minus the side-bands (1.0<|RA|<1.8) is plotted.

The peaked structure is mostly due to the detector resolution.



Improved energy definition is possible using the shower-fitting method (work in progress) which is computing intensive.

The plot to the right is an example for one scan.

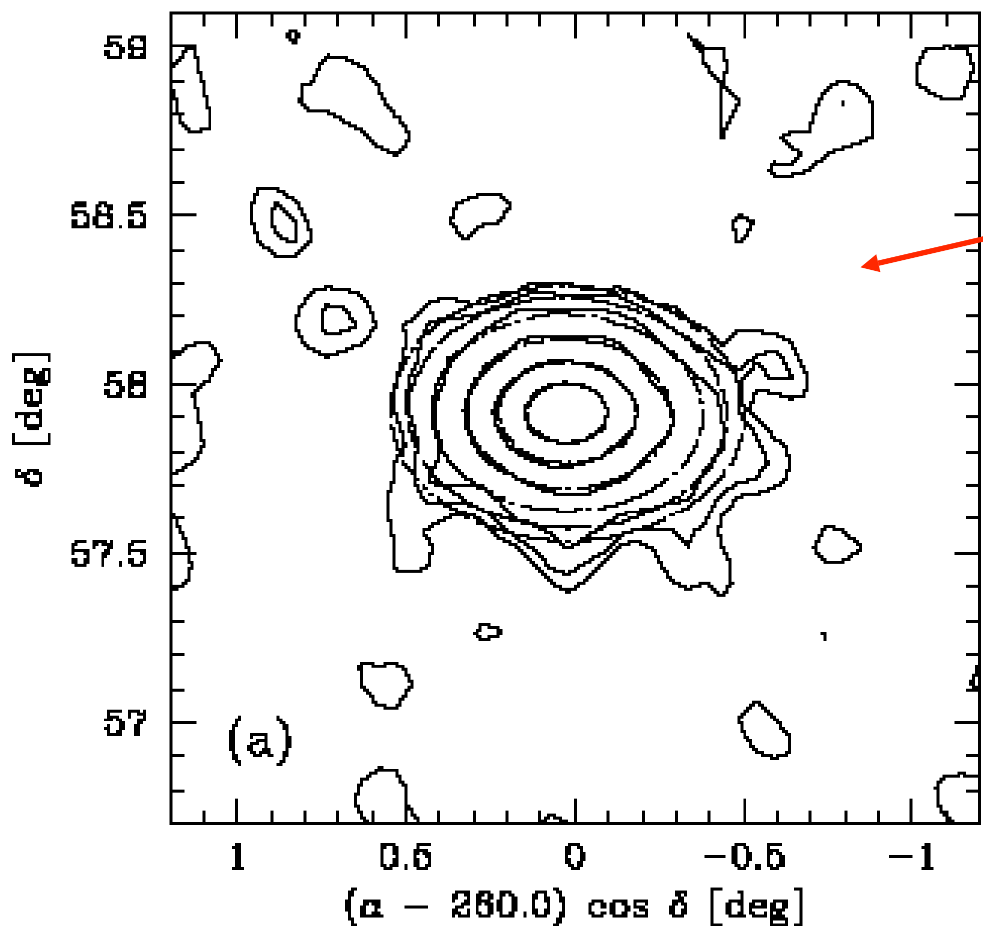


Sources of Error:
“What might fake this signal?”

Major concern is that background light from either foreground stars or the integrated light from Draco itself is lowering the effective threshold, thereby accepting more cosmic rays in the Draco region.

This effect is being simulated.

The pictures below show the light contour map and a digital picture of the Draco region obtained by Sloan. We are implementing this in our simulations.



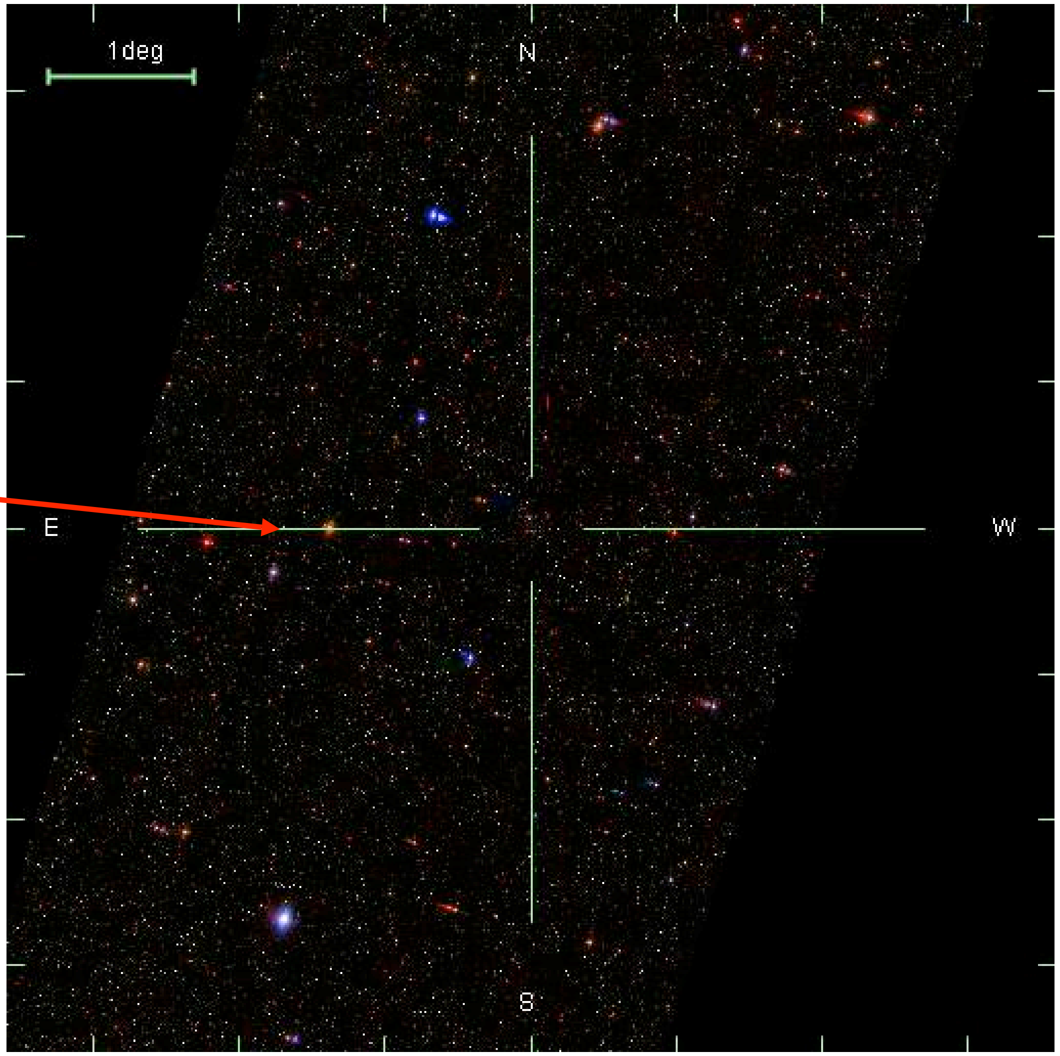
SDSS

map

and

picture

(There is a star at ~ -1.5^{o} in RA.)

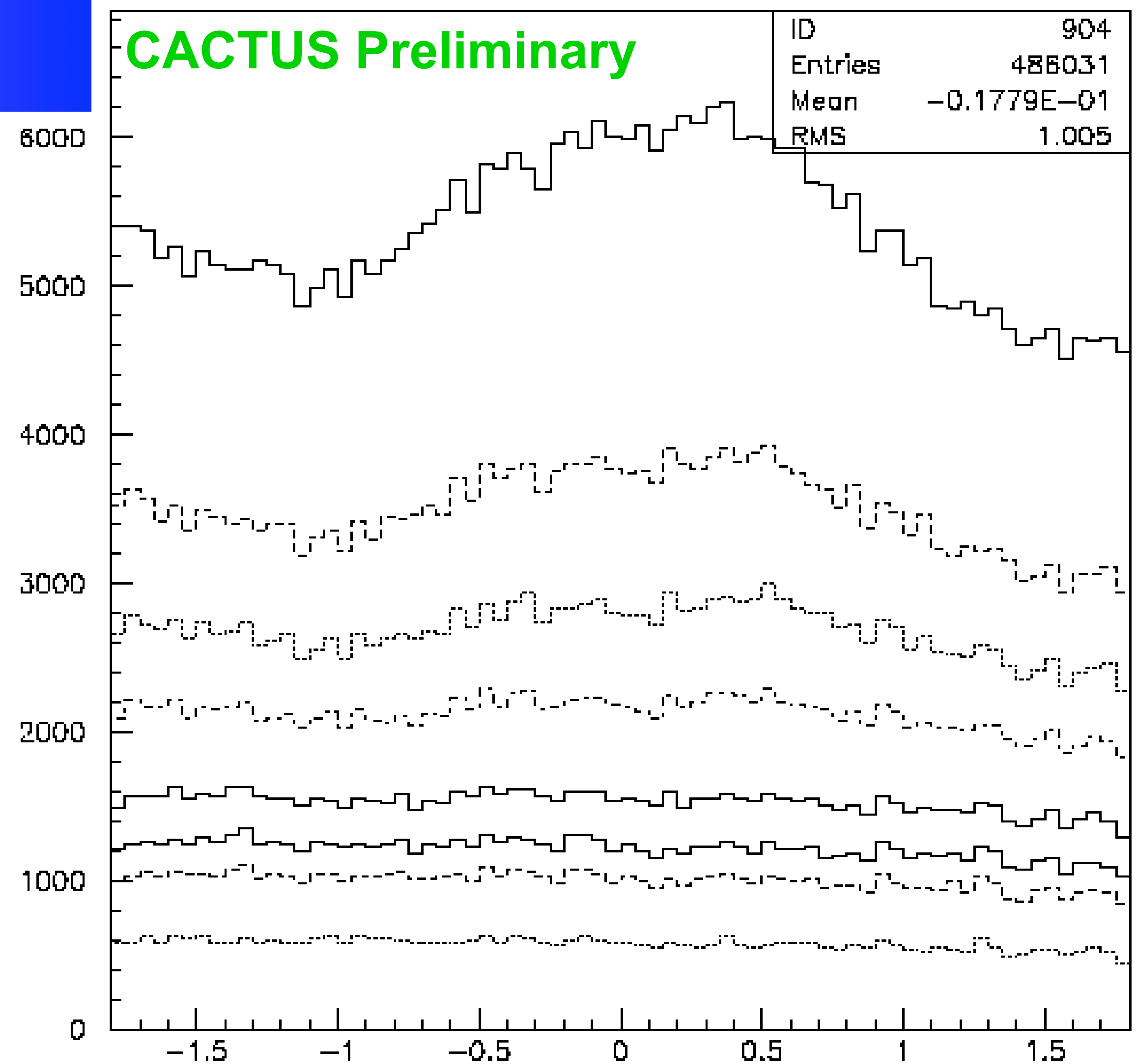


Summary

1. We have measured the Crab spectrum in the region above EGRET and below ACTs.

2. We have observed an excess of showers from the direction of Draco. Still testing the robustness of the excess. Work to be done:

- Full shower fit analysis.
- Trigger threshold analysis.
- Study of sensitivity to noise assisted triggers near threshold



<u>Plans:</u>

Observe Leo II and Sextans in Fall.

Further calibrations with Crab in Winter.

Return to Draco in Spring

Further update and published results expected by year end.

We welcome collaborators!

Acknowledgments

- We thank the Vice Chancellor for Research, Dr. Barry Klein, and the Dean for MPS, Dr. Winston Ko for critical support in the form of seed funds. We extend our gratitude to the Committee on Research at UC-Davis for a grant to implement our hardware at CACTUS.

- We thank the Office of the President of the University of California for supporting us with a grant for the development of the electronics for CACTUS.

- We are indebted to Southern California Edison, and Mr. Judd Kilminik in particular, for allowing us to use the Solar-2 site.

- An original grant from the Keck Foundation and Dr. Tumer from UCR paid for the mechanical and civil engineering aspects of converting Solar-2 into an ACT.

- The senior Electronics Engineer at UC-Davis, Mr. Britt Holbrook, takes a large part of the credit for the successful conversion and operation of CACTUS.

- We also wish to acknowledge the efforts of numerous undergraduate and graduate students who worked part time in the desert to make CACTUS into a reality.
- We are grateful to Prof. Alan Zych of UCR for the loan of 50 phototubes.